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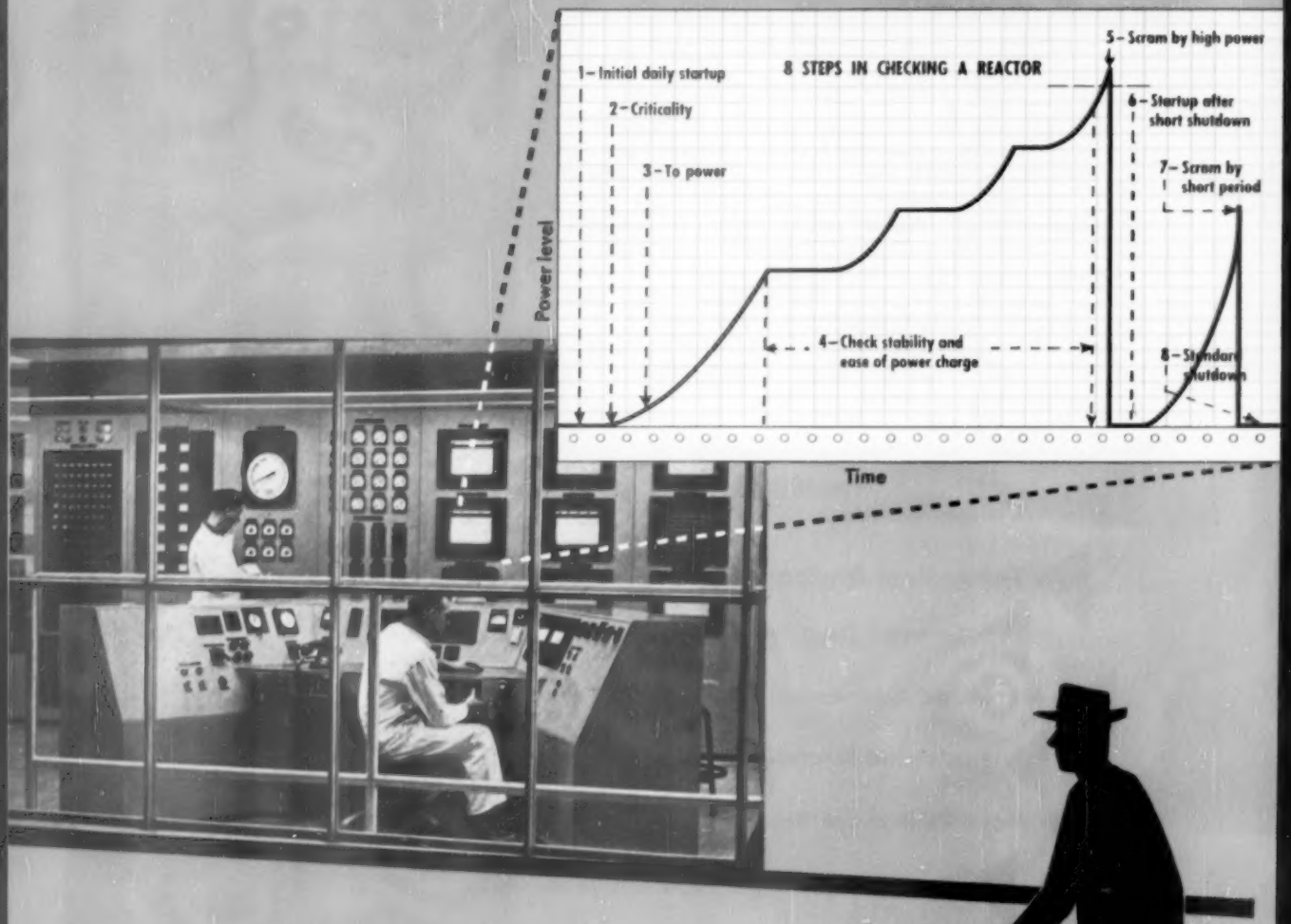
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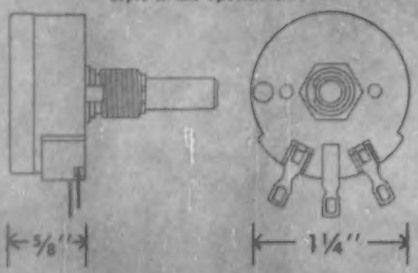

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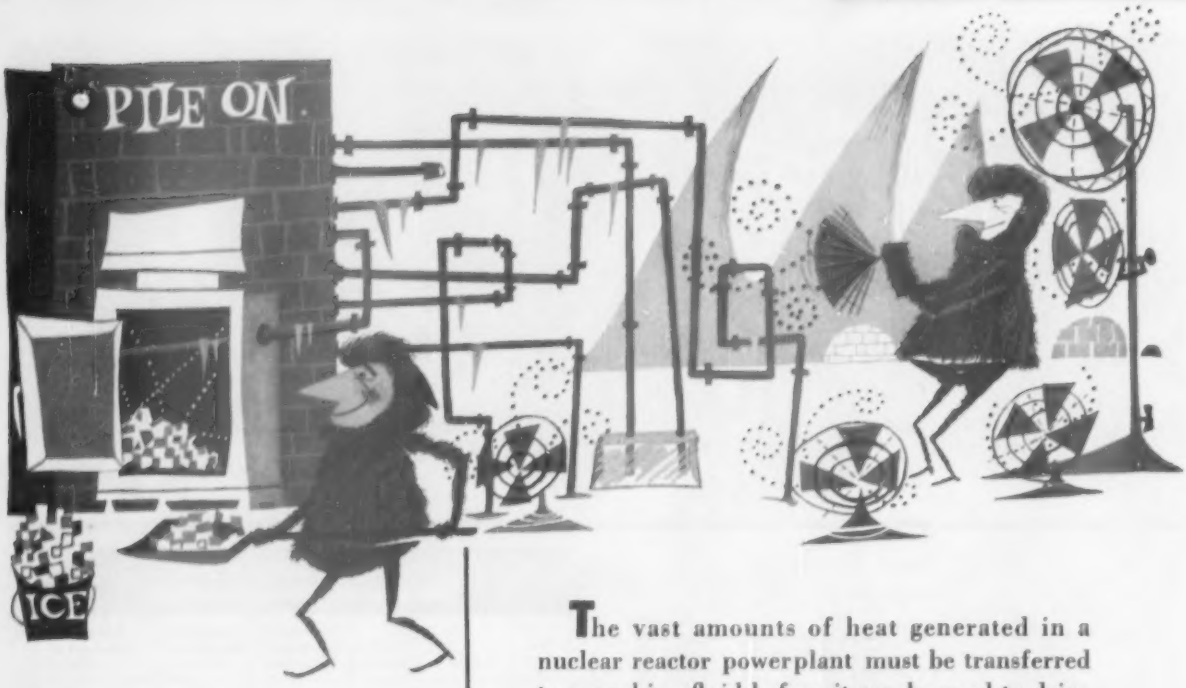

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ROUNDUP of Key Developments in Atomic Energy

LATE NEWS and Commentary

Bilateral Agreements

This is the year of nuclear diplomacy the world over. With interest in atomic energy fired in countries large and small (including places such as Thailand which set up an atomic energy committee in anticipation of a visit from the U. S. Joint Committee on Atomic Energy), attention is being turned to means of getting programs under way.

Biggest need is for information and materials. The need obviously varies according to the state of development in a particular country. Nations that already have one reactor or are well on their way towards building one (such as in Western Europe) are after very practical information on specific types of reactor systems. They want data on how various materials actually withstand reactor operating conditions (e.g., radiation damage, corrosion effects, rates of heat transfer, etc.), data on fuel element design and performance, data on how parameters such as temperature and poisoning affect the nuclear performance of reactors.

Countries such as India and Japan are apparently more interested in getting scarce reactor materials and basic information so that they can evolve their own technology. There is one school of thought in Japan, however, that would prefer to import considerable assistance for building a small power reactor so that they could jump right in and get their feet wet. This school is thus more interested in component and materials cost data.

To get assistance such as enumerated above, a number of countries are turning to the U. S. It's expected that "agreements for cooperation" as required by the Atomic Energy Act of 1954 will be concluded in 1955 with: Australia, Belgium, Brazil, Canada, England, India, Japan, the Netherlands, and Turkey.

Actually because of the important role that the peacetime atom is playing in international politics, the U. S. is in competition with the British and other countries possessing strategic nuclear materials on working with other nations. For example, because of the commitments involved in an agreement with the U. S., it is reported that were it not for India's early need for heavy water she might have bought it elsewhere (see p. 8).

Some countries in seeking agreements are after whatever might be made available to them. Others are more specific in their interests. An example of the latter is one European nation that wants help on building a materials testing reactor.

The success of the "atoms for peace" program is said by many to hinge on the degree to which cooperation is unencumbered.

•

New Reactor Director

Three months after the resignation of L. R. Hafstad as AEC's reactor director, AEC filled his spot last month with his deputy, W. Kenneth Davis, former manager of research for California Research and Development Co. Among those understood to have been considered for the post were Alvin C. Graves of Los Alamos and Rear Admiral H. G. Rickover, chief Navy nuclear man.

With responsibility for AEC's programs for civilian, naval and aircraft reactors, Davis also takes on the key task of fostering the development of a nuclear industry. In contrast with Hafstad, Davis is known to be opposed to dual-purpose reactors as the basis for an industry. He is also said to be in favor of industry's taking on an important role in the chemical processing field, and he

might be expected to look favorably upon a proposal under AEC's "power demonstration" program that would include a plan for fuel recovery.

•

Con Ed Plans Although it is not expected that the company will submit a proposal under AEC's "power demonstration" program, Consolidated Edison of N. Y. is expected to file by April 1 an application for a license to build its nuclear power plant on the Hudson River. The company wants to be the first to get a license under Sec. 104b of the new law.

It appears assured that Babcock and Wilcox will get the contract for this first 100% privately owned power reactor. It is understood that B & W proposed a pressurized light-water reactor with an "improved" fuel element, Westinghouse pushed its interest in pressurized-water and homogeneous reactors, and General Electric its interest in boiling-water reactors and an "improved" Hanford reactor.

•

Geneva Conference U. S. plans for participation in the UN nuclear energy conference next summer are jelling. George Weil, former AEC assistant reactor chief, has been named to be technical director of AEC's Office for International Conference. Paul W. McDaniel, AEC's deputy director of research, will be in charge of reviewing U. S. papers submitted for the conference.

It is expected that several hundred abstracts of proposed papers will be submitted to AEC by the March 11 deadline. From these, complete papers will be asked for by May 15, the UN deadline for abstracts. Only a small percentage of the papers AEC received will be recommended for oral presentation at the conference. Determination of this will actually be by reviewers set up under Walter Whitman, secretary general for the conference.

AEC will also run an exhibit at Geneva with American organizations participating in it. It is expected that as part of the exhibit Oak Ridge National Laboratory will build a swimming pool reactor.

•

Naval Nuclear Power U. S. Navy statements that it will use nuclear power extensively are backed up by continued growth of submarine program. First nuclear-powered submarine, the *Nautilus*, is winding up deep-diving and armament tests at sea. Second, the *Sea Wolf*, will be launched no later than May, although prototype of its SIR reactor won't be operating until this summer. Third and fourth are being built under fiscal-1955 shipbuilding program. Fifth, sixth, and seventh will be built with funds from fiscal-1956 budget being considered by Congress.

Even further expansion is indicated by program to decentralize building. General Dynamic Corp.'s Electric Boat Div., has built first two nuclear submarines, will probably build a third. But at least one will be built at Portsmouth naval shipyard in Maine. And Navy has already said that Mare Island naval shipyard in California will be a construction center.

•

18-million kwh for Sale Confirming NUCLEONICS' report that General Electric is planning to sell electricity generated with prototype submarine-intermediate-reactor power (NU, Jan. '55, p. 10) is a letter written by J. D. Anderson of AEC's Schenectady office. He informed utilities in that area that power would not be firm but would vary from 0 to 10,000 kw. As much as 6-million kilowatt-hours per year may be available for three years, starting late this summer.

British Aim $840-Million at 12 Power Plants by '65

Faced with dwindling coal reserves and rising power costs, Great Britain is embarking on a 10-year program that will result in 12 nuclear power stations with 16 reactors operating by 1965. By then, the $840-million project will have added 1½- to 2-million kilowatts to British generating capacity, and nuclear power will be providing 25% of new generating capacity added each year.

While the program is provisional and subject to change, the government White Paper announcing its presented a clear detailed picture of how Britain hopes to achieve economic nuclear power. First, Britain is concentrating on two reactor types. Gas-cooled reactors similar to the ones now under construction at Calder Hall would be built first, and would provide both power and plutonium. Later, liquid-cooled thermal reactors would provide higher thermodynamic efficiency, but would require fuel enriched with the plutonium provided by earlier reactors.

Breeder reactors and other types —homogeneous or thorium-fueled— are not expected to be developed until after 1965. But research and development of these types will not be neglected until then—witness the fast breeder power reactor now being built at Dounreay, Scotland. Funds for this development are not included in the White Paper totals.

The White Paper timetable for construction of 16 reactors by 1965 is shown in the table on this page. Costs for these first eight units can be estimated from the Calder Hall plant, with two gas-cooled reactors. Construction there will total $42- to $56-million, and original fuel loading will cost about $14-million. A new fuel charge will be needed every 3–5 years.

The nuclear power stations would be built by industry, but would be operated by the government's Electric Authorities. The authorities blanket the British Isles, including Northern Ireland. The Northern Ireland Ministry of Commerce has already invited applications from engineers to fill a "post connected with developments in the use of nuclear energy." The engineer appointed will train for about two years at the British Atomic Energy Research Establishment at Harwell.

Will the program provide economic power? The White Paper says it can—it estimates that the first stations can produce power for 7 mills/kilowatt-hr. It bases its estimates on a station life of 10–20 years at a load factor of 80%. But it reduces power cost initially by allowing credit for plutonium at "thousands of pounds (sterling) per kilogram." This price is based on civilian use of plutonium; it is expected to drop eventually, but the drop would be balanced by improvements in plant efficiency.

Another uncertainty in the power-cost estimate is that it's based on even the first plants being more efficient than the Calder Hall unit. Costs are based on extracting as much as 3,000 megawatt-days of heat from every ton of fuel. To quote the White Paper: "There is as yet no practical experience of this level of irradiation at high temperatures and the metallurgical behaviour of the fuel elements is uncertain. But there are many lines of development which should overcome such metallurgical defects as may appear."

Another factor influencing costs is fuel processing. Since processing for the first plants will be carried out at existing facilities, costs are known. As the program progresses, new facilities will be needed. "Big reductions" in processing costs are expected when a new fuel-fabrication plant and a new chemical processing plant for used fuel are eventually completed.

Fuel cost. If efficiency of the early reactors is about 20%, each will produce about 250–500 Mw of heat for 50–100 Mw electric capacity. Taking burnup as 3,000 Mw-days/ton, the first loading would be 73–146 tons of natural uranium for 3 years operation at 80% load factor, or 121–243 tons for 5 years. Extending this rough calculation on the basis of the $7-million loading charge for a Calder Hall reactor, you get a cost for fabricated natural uranium fuel ranging from $15 to $50 per pound.

Can Britain afford this program? Financing should not be a burden to British economy. As the White Paper points out, addition of nuclear power will reduce the need for other sources of power. Thus, investment in conventional stations and in coal mining will be cut.

Other benefits. Britain is also counting on the 10-year program to turn a present stumbling block into advantage. Construction of the first plant under the program won't start until 1957 because industry lacks the training to do the job. By establishing a long-range program, the government hopes to hasten training by increasing industrial interest. An experienced industry, backing well-developed nuclear power plants, would enable Britain to cash in on a valuable export trade.

Most of the burden of training industry's engineers has fallen on the Atomic Energy Research Establishment at Harwell. Last month, Manchester University inaugurated a new six-week course in nuclear engineering.

Timetable for Britain's 10-Year Program*

No. of stations	*No. of reactors*	*Begin constr.*	*Begin oper.*	*Type of reactor*	*Cost† ($10⁶)*	*Elec. output (Mw)*
2	4	1957	1960,1	Gas cooled	84–98	400–800
2	4	1958,9	1963	Gas cooled, improved	>84–98	
4	4	1960	1963,4	Gas cooled (?), higher power	350	>1,000
4	4	1961,2	1965	Liquid cooled, enriched (?)		

* Not including the experimental units at Calder Hall and Dounreay.

† Construction and installation costs shown. Total initial loadings of fabricated fuel might amount to $112-million. Capital costs of required new processing facilities would run about $84-million. Prototype development capital costs might be $84–112-million. Since plants to be completed after 1965 are not included in this program, more than $840-million will be spent during the next 10 years.

UN Works on Meeting, U. S. Atom Plan Grows

While the United Nations works to build its August international atomic energy conference on the agenda and rules of procedure set down by its advisory committee (NU, Feb. '55, p. 5), the United States is implementing President

ROUNDUP

Eisenhower's atoms for peace plan through bilateral arrangements. In February, the Atomic Energy Commission announced the sale of 10 tons of heavy water to India; negotiations continued with Belgium, with hints that Belgium might get the first power reactor with the U. S. providing assistance; and Rep. Sidney Yates (D, Ill.) introduced a resolution in the House of Representatives calling for construction of a power reactor in Hiroshima, Japan.

Heavy water for India. A subcommittee of the Joint Committee on Atomic Energy recommended that heavy water be provided for an Indian research reactor to be built at Trombay. Its recommendation, based on a Far East junket between sessions of Congress, was contained in a trip report released at the same time as the AEC announcement that it had agreed to an Indian government request for sale of the heavy water. The Trombay reactor will be operating by 1957; it will cost $2-million.

Belgian, Japanese reactors. The idea of the U. S. providing a reactor for Japan isn't new; AEC Commissioner Thomas Murray suggested such a step almost a year ago. But the Yates proposal raises the question of what nation will get the first U. S. aid towards nuclear power.

Under wartime agreements, the U. S. owes Belgium information and materials that can be applied to peaceful use of atomic energy. This is partial recompense for Belgium's wartime cooperation in providing Congo uranium ore. Until the Atomic Energy Act of 1954 was passed, the U. S. couldn't legally provide all it had guaranteed to Belgium.

If Congress passes the Yates proposal, the administration would still have to negotiate with the Japanese government to set up a specific agreement. It's unlikely that Japan will get the first U. S. aid.

UN conference agenda. After starting with plenary sessions, the conference will divide into simultaneous sessions and then conclude with a final plenary session. The topical agenda on which conference planning is based provides the following breakdown of time (hours):

First plenary sessions. Need for a new power source, 5½; role of nuclear energy, 3; building of a nuclear energy enterprise, 3; health and safety aspects, 3; production and use of isotopes, 3; problems relating to large quantities of radioactive substances, 3. The aim of these plenary sessions is to provide the broad base for further discussion.

Simultaneous sessions. Reactor sessions include: research reactors, 9; power reactor systems for development, 9; power reactor prototypes, 6; raw materials technology, 9; reactor chemistry and metallurgy, 9; liquid-metals technology, 3; waste treatment and disposal, 3. Reactor physics would be considered in eight 3-hr sessions; chemistry and metallurgy in seven 3-hr sessions; biology and medicine in eleven 3-hr sessions; and industrial and research applications of isotopes in five 3-hr sessions.

Closing plenary session. This 3-hr adjournment will be devoted to a consideration of thorium, reports on measures of assistance to other

Washington Report

Considerable attention is being paid in Washington these days to two facets of international atomic energy activities—(a) the worldwide race for developing commercial nuclear power plants and (b) the "atoms-for-peace" program.

Contenders in the power race have been considered to be the U. S., England and Russia. From the viewpoint of getting practical plants built the British have been thought to be in the lead. If there was any question about it, the clincher was applied last month when they announced a bold program of putting 16 large power reactors into operation by 1965 (see p. 7). This dwarfs the U. S. five-year program of building five experimental reactors, and leaves in the dust the one Russian 5,000-kw plant.

The fact that we are in a race was emphasized by two members of the Joint Congressional Committee on Atomic Energy. Said Sen. Pastore (D, R. I.): "I have always felt that we are in a race with other countries of the world in achieving this objective of producing electric power by use of atomic energy." Said Rep. Durham (D, N. C.): "If we have to mess around here for another period of years, somebody else might beat us to it."

Presumably there are three goals in this race: (a) usual competitive desire to be first, (b) demonstration to the world of interest in peacetime atom, and (c) competition for the foreign atomic market. On the latter, the British reportedly feel they can sell $6-billion worth of nuclear exports in the next 20 years.

On goal b, a Joint Committee subcommittee, recently returned from the Eastern Hemisphere, reported last month that it found an "overwhelming" response to the U. S. atoms-for-peace program. The group urged that bilateral agreements with various nations be set up promptly.

One legal barrier that may interfere with assistance to foreign groups by nongovernmental U. S. organizations and individuals is Sec. 57 a (3) of the Atomic Energy Act (see pgs. 49, 51). According to the Cole report on the law, even in unclassified areas this requires that anyone wanting to teach abroad, to sell unclassified services or parts of facilities, or to help build facilities, must have a ruling from AEC that such activities are not inimical to the interest of the U. S.

This provision has been attacked on the basis that the Government should have no more control over unclassified activities in the atomic energy field than it does in other fields.

nations by those attending the conference, and closing remarks by the conference president.

To add to conference coverage of the field, a series of evening lectures is also planned. Topics include accelerators, elementary particles and mesons, nuclear forces, nuclear structure, the neutron, isotopic dating, free radicals, and new elements. "Scientists of world repute" will be invited by the UN to deliver these lectures.

APDA Doubles Budget, Starts Component Tests

Doubling its budget for last year, Atomic Power Development Associates will spend $3,815,000 in 1955. To date, the 33 member companies of the AEC-approved nuclear power study group have contributed about $3½-million total to the study since it started in 1951.

Reason for the jump is that the group has reached the point where results of paper studies of its proposed sodium-cooled breeder power reactor can be tested on actual components. Thus this year's budget includes the cost of full-scale pumps, piping, heat exchangers and other devices for handling liquid metals at high temperatures. Also included is a high-temperature steam generator being built by Babcock & Wilcox.

A new laboratory will be established at Detroit Edison's Delray generating station so that the components can be tested under reactor plant conditions, but without use of actual nuclear fuel.

Columbia, MURA, Israel Will Add Accelerators

Construction has started on a physics research building at Columbia University, New York, which will house a 6-Mev Van de Graaff accelerator. Plans for two other accelerators have been announced by Midwestern Universities Research Association (MURA) and by Weizmann Institute for Science in Israel.

The Atomic Energy Commission is contributing $295,000 to the cost of the Columbia laboratory, and will supply the accelerator on loan. Cost of the High Voltage Engineering Corp. machine will be about $450,000. The machine will be

About the Industry

Insuring reactor facilities against any possible catastrophic failure is one of the biggest problems facing the atomic energy industry. So far, private insurance companies have balked at underwriting this risk unless some way is found to establish a multimillion-dollar fund to cover possible claims.

Directly related but perhaps overlooked are problems raised by the need for insuring workers against possible occupational injury or disability caused by radiation. In many states this is required under workmen's compensation laws.

That this insurance can be a major cost item to a company using radiation extensively is shown by recent occurrences in New York. State law requires that insurance be carried either with a private underwriter, with the state insurance fund (which charges an added 100% for premiums), or by the company itself in the form of securities deposited with the state. Premium rates are set by a rating board composed of representatives of insurance companies doing business in New York.

One company engaged in preparing radioisotopes for medical and industrial use applied for compensation coverage. The rating board set premiums for this company's radiation workers at $5 per $100 of payroll; 5 months after an appeal, this was reduced to $3.40/$100. For comparison, the secretarial rate averages 17 cents/$100; the chemical industry $3.40; steel erection $18.80.

Because they had no actuarial experience on such a risk, more than a half-dozen private insurance companies would not write a compensation policy. The company was forced to enter the state fund, paying an actual $6.80/$100 premium. Since payroll is the major expense of this company, this has the effect of cutting its profit margin by more than 5%.

The one silver lining is that after a year in the state fund, the company can ask to be assigned to a private underwriter if it still can't get private coverage on its own. This would eliminate the 100% override. And, as years of actuarial experience are built up, perhaps the rate can be reduced on the basis of a good safety record.

But any safety record will have to combat a far-reaching provision of state law adopted in 1947—that any disease or disability attributable to radiation exposure will be considered a compensation claim if incurred by a worker exposed to radiation. There is no time limit for filing a claim, and the burden of proving that the exposure was not harmful falls on the employer. Even compliance with the codes going into effect in New York do not give the employer an absolute defense against damages. The theory is that an employee who is particularly sensitive to radiation still is entitled to full compensation for injury.

The atomic industry can hasten insurance-rate reduction and gain acceptance as a risk by combating actuarial hesitancy with facts: safe operation of at least 22 U. S. reactors for a total of over 134 reactor-years since 1942; AEC's safety record that won the National Safety Council merit award in 1953, and includes an injury rate less than a third that of over-all industry, with only 4 radiation injuries since 1947 outside of weapons tests; plus stringent regulation by State and Federal authorities (see editorial, page 17).

used in systematic investigation of nuclear energy levels and to develop methods for measuring cross sections.

The Van de Graaff will be the third accelerator at Columbia.

Weizmann Institute is acquiring a 3-Mev accelerator for study of nuclear reactions involving high-energy protons.

MURA, an organization formed in 1953 by eight midwestern universities with the aim of setting up a central high-energy-physics laboratory, plans to have a 20–30 Bev accelerator in operation by 1961. The machine would be comparable in size to one now being designed at Brookhaven National Laboratory, but would use a new design principle (see p. 74).

Members of MURA include the Universities of Illinois, Iowa, Michigan, Minnesota and Wisconsin, Purdue U., Indiana U., and Iowa State College. Argonne National Laboratory, Wayne U., and the University of Chicago are cooperating in MURA design studies headed by D. W. Kerst.

AEC Budget Total Down, but Operating Cost Rises

According to the budget for fiscal 1956, Atomic Energy Commission expenditures will total $2-billion—a drop of $50-million from fiscal 1955. But budgets submitted to Congress don't give too true a picture of how much the agency will actually spend. For example:

AEC is asking only $1,129,900,000 in new money. All this goes for operations. Added to it will be $221,845,000 unspent from previous

Reactor News

Canada plans industry power prototype. With the intention of creating a new Canadian industry to supply domestic and foreign commercial markets for reactors and their components, the Canadian government has invited industrial firms to propose design, construction, and operation of a 20-Mw (elec.) prototype power reactor for operation starting in early 1958. The prime contractor will be expected to share in the project's cost. Chalk River will supply nuclear data.

Under a set-up similar to the AEC-Duquesne deal on the PWR (NU, April '54, p. 78), a utility would provide the power plant and site, as well as operate the entire plant. The utility would purchase the steam and use the power in an existing system.

The reactor probably would use pressurized heavy water as primary coolant and moderator, zirconium-clad natural-uranium fuel elements, and some plutonium to reduce core size.

In the meantime, work is continuing at Chalk River on NRU, which is due to operate in June, 1956. It will be used to produce plutonium as well as provide facilities for testing components for the prototype power reactor and an eventual 100-Mw (elec.) reactor.

Britain tests Calder Hall pressure shell. One of the two 40-ft-diam. by 60-ft pressure shells to be used to contain the Calder Hall reactors reportedly has undergone its initial heat test. Formed of several-inch-thick shaped and welded steel plates, the shell briefly was heated inside to check distortion due to the temperature differential. Other tests will use pressure and vacuum to detect leaks.

Hydrocarbon coolant-moderator proposed. North-American Aviation studies on a reactor using a hydrocarbon for moderator and coolant are believed being considered for experimental development. Although radiation-induced decomposition problems could arise, the relief from corrosion and pressurization difficulties encountered with water reactors is reported to make hydrocarbon use a promising possibility. Use of terphenyl is being studied.

AMF to build first industry-owned reactor; North American gets Armour contract. American Machine & Foundry Co., after being awarded contract for 0.1–1-Mw swimming-pool-type research reactor for Battelle Memorial Institute, has proposed that about 10 industrial firms join AMF in sponsoring a similar AMF reactor facility for their own research purposes (NU, Feb. '55, p. 5). Operating cost will be about $125,000/yr.

Both of these new reactor facilities will be somewhat similar to those planned at the University of Michigan and Pennsylvania State College, for which Oak Ridge's Bulk Shielding Reactor is the prototype.

Battelle's reactor facility, which is scheduled for operation in February, 1956, will cost about $1.5-million.

North American is building a 50-kw water-boiler reactor for Armour Research Foundation (NU, Oct. '54, p. 78). Seven firms have signed as sponsors of this program; about eight more are expected.

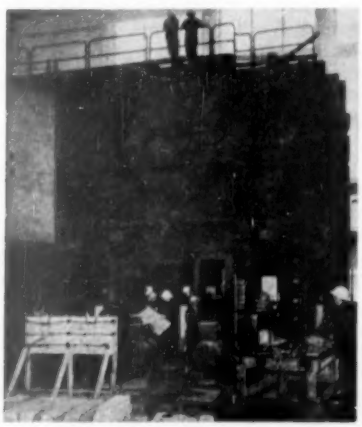
Reactor kinetics due for more experimental appraisal. In a program aimed at improving inherent safety of reactor designs, Phillips Petroleum Co. next June will begin testing kinetics of various reactor configurations. A new facility to be built at the National Reactor Testing Station will be used. The facility, for which construction bids have been made, will consist of a test-pit building and structures for control, instruments, and mechanical equipment.

appropriations last year for plant and equipment and $170.7-million of unused 1955 operating capital. Thus, AEC will have $1,513,672,000 to spend for operations in fiscal 1956. This is allotted as follows (all figures in millions of dollars, fiscal 1955 figures in parentheses for comparison): source and fissionable materials, 909.9 (728.7); weapons, 308.3 (261.8); reactor development, 118.2 (94.6); physical research, 43.6 (40.0); biology and medicine, 27.0 (27.0); community, income of 2.2 (income of 2.0); program direction and administration, 33.2 (33.4); and security investigations, 5.7 (8.4).

This totals $1,443,800,000. The difference between this operating cost figure and funds available is taken up by inventory increases, working capital changes, and obligated balances for work to be done after fiscal 1956.

For an estimate of how much AEC will spend, take the $1.4-billion figure as being closest.

In addition to operating costs, AEC also normally asks for money to finance additions to its plant and equipment—capital expenditures. It had an excess of $446-million allotted in fiscal 1955; after transferring part of this to the operating budget, it still has $214-million for fiscal 1956. Included in projects this will finance are $59.4-million for production plant improvements, $34.1-million for prototype military reactors, and $39.9-million for developmental power reactors.



CANADA'S NRU research reactor is being pushed for June '56 completion. Construction operations are shown here. Rather than have H_2O coolant enter core as in NRX, higher-flux NRU will have D_2O circulate to heat exchangers outside reactor

Industrial Applications

Continuous weighing of light materials. A new weighing method based on radiation absorption seems to offer the first satisfactory method of weighing bagasse—the residue after extracting the juices from sugar cane. Bagasse is bulky and contains about 50% water. Its particle length averages less than 1-in. Moving bagasse is weighed with an error of under 2% by measuring its radiation absorption as it drops off a conveyor belt at the end of the sugar-extraction process. Weight is calculated from absorption of either Co^{60} or Ce^{137} radiation. Bagasse weight is important as it together with juice weight gives the amount of sugar cane milled. Because incoming sugar cane contains dirt and rock actual cane weight has previously had to be estimated. It was impractical to weigh bagasse as it moved along a conveyor belt at the end of the process. The new method has been tested for two years by the Hawaiian Sugar Planters' Association experiment station. A full-sized commercial model is now going into operation. Possibility of weighing raw sugar in same way is presently under study.

Rubber vulcanized by radiation. Gamma radiation from cobalt-60 has been used to vulcanize both natural and synthetic rubber. Heat and chemical agents were not needed. Quality equal to or better than that obtained with conventional vulcanization is attained, according to the Air Research and Development Command, Baltimore, Md. Method is most promising for special rubbers.

Radioactive sand plots silt movement. Common problem in keeping shipping channels open, preventing floods, and maintaining sand at beaches is need to know the silt distribution pattern. Results of a distribution study using artificial radioactive sand have been called very promising by the British Atomic Energy Research Establishment and Government Hydraulic Station personnel who carried out the test. Sand was traced for up to 13 miles from its dumping spot in the Thames river. Sand was made by first producing glass containing scandium. Glass was ground to 0.07 mm to match local mud. It was then reactor irradiated to yield 85-day Sc^{46} that emits 1.12- and 0.89-Mev gammas. About 0.22% of this sand was mixed with natural mud and lowered to the river bed. Activity was traced for two weeks, using underwater detectors.

New static eliminator being developed. Current method for dissipating static electricity is ionizing the surrounding air, so charge will leak off. A new approach, supplying air of one polarity to neutralize the charge, is being developed at the U. of Arizona, under sponsorship of U. S. Radium Corp. and Wesix Electric Heater Co. Unipolar air is made by ionizing air with polonium or radium-D foils and capturing the unwanted ions on charged plates. Radioisotope sources are best of all available ionization means, as they have best controllability and do not produce ozone. Air-ionization importance in comfort and physiology is under study (*Heating Piping and Air Conditioning*, Oct. '54, p. 120). Inhabited-room air has fewer negative ions than does outdoor air. By supplying them it is thought that outdoor comfort can be restored.

ROUNDUP

News in Brief

Offer intensive course on reactors, radiation. For a $200 tuition fee, an engineer without experience in nuclear technology can update himself at a two-week course on nuclear reactors and radiations in industry at the University of Michigan. The August 15–26 sessions will progress from lectures on elementary theory to demonstrations of industrial applications. Deadline for applications is June 1; write W. Kerr, Dept. of Electrical Engineering, University of Michigan, Ann Arbor, Mich.

Nebraska group to study nuclear power. Consumers Public Power District of Columbus, Nebraska, is undertaking a one-year, $100,000 survey of nuclear power under AEC's industrial participation program.

Plan background course for top management, conference on atomic energy in industry. A "thorough but nontechnical course in atomic energy designed for business executives who are not scientifically trained" is being sponsored April 24–30 by the National Industrial Conference Board, 247 Park Ave., New York 17, N. Y. Lectures, discussions, and demonstrations will be held at the Westchester Country Club. Fee is $465; emphasis of course is on industrial uses and such problems as securing qualified personnel, public relations, and business potential. October 26–28, NICB will hold its fourth annual atomic energy conference.

Stanford doubles available radiation. Adding a second 2,000-curie cobalt-60 source to its irradiation unit, Stanford Research Institute will be able to halve the time needed for experiments. Source was obtained from Brookhaven National Laboratory.

Yale gets $3-million for biophysics research. The John A. Hartford Foundation has awarded a $3,160,000 grant to Yale University to support biophysics research. Money will support a new $460,000 laboratory at Valhalla, N. Y., for 15 years. E. C. Pollard will head Yale's new biophysics department; F. Hutchinson will be resident director at Valhalla next year. Part of research program will be aimed at radiation processing of foods.

Choose PWR construction contractors. Duquesne Light Co. has selected Burns & Roe, J. Rich Steers, and Hatzel & Buehler as general contractors for construction of the pressurized-water-reactor power-plant facilities.

Consulting firm expands space. Nuclear Development Associates has been renting space in White Plains, N. Y. Now, the firm has bought (a) an 1,100-acre tract near Poughkeepsie where it will build a small, secluded laboratory; (b) a four-story Consolidated Edison building in White Plains, with 55,000 square feet compared to present 18,000.

East Germany bids for West's scientists. R. Havemann, director of the Physical and Chemical Research Institute of Humboldt University in East Berlin, used a recent newspaper article to invite West German scientists to join the research staff being created to work with a planned research reactor.

British dump 1,500 tons of radioactive waste into Atlantic. What is probably the biggest dumping of radioactive waste into ocean waters has been carried out by the British. Included in 1,500 tons dumped somewhere southwest of Lands End where water is 7,200-ft deep was bulky used apparatus. But all materials were in containers designed to last at least 30 years. Ocean dumping was necessary after miners objected to planned use of disused coal mines for storage.

Select site for first Australian reactor. An area of 150 acres about 20 miles south of Sidney has been set aside as the site for Australia's first research reactor. Complete research facilities are planned. Coastal location facilitates dumping of wastes at sea. Besides isotope production and research on nuclear power, the new center will engage in thermonuclear engineering.

Forum, Stanford Research plan meeting. Atomic Industrial Forum and Stanford Research Institute will jointly sponsor a meeting April 4 and 5 on "Atomic Energy—the New Industrial Frontier." San Francisco sessions will include discussions by G. Seaborg, B. Morgan, E. Teller, J. Johnson, C. Starr, R. P. Petersen, and M. Calvin.

Germany setting up nuclear institute. By 1956 Bonn University will have an Institute for Nuclear Physics equipped with a 30-Mev synchrocyclotron.

AEC power needs—still rising. In fiscal year 1956 (starting July 1) AEC will get 12.8% of the total national sales of electric power to ultimate consumers. This is a 50% increase over fiscal '55. But AEC load will level off in fiscal '57 while national total continues its climb, so AEC share will decrease then.

AEC asks industry to review regulations. Before it promulgates regulations affecting any industry, AEC is asking industry to comment at roundtable conferences. First group, 17 power company officials, will discuss licensing.

AEC releases fall-out data. That radioactivity blanketed an area 220 miles downwind from the H-bomb test last March was announced almost a year later by AEC. Its February 15 announcement said that completely lethal doses would be received by persons not taking precautions in an area 140 miles in length, up to 20 miles wide. Time required: 36 hours. But AEC spelled out that precautions like taking shelter, washing off fallout dust, would be effective.

Von Neumann appointment finally gets public hearing. On February 9, Sen. Clinton Anderson announced that the Joint Committee on Atomic Energy planned a March public hearing on confirmation of President Eisenhower's third appointment of John von Neumann to the Atomic Energy Commission. The scientist was first appointed last fall, received an interim appointment when Congress failed to act then, and was reappointed this January.

Two more regions get ORINS symposia. Under its program to make Oak Ridge staff resources available to schools and colleges, Oak Ridge Institute of Nuclear Studies is planning its third and fourth regional symposia. On March 5, University of South Carolina sponsors "Science and Atomic Energy" at Columbia, S. C.; on March 11 and 12, University of North Carolina, Duke U., and North Carolina State College will divide sessions on "Atomic Energy in Science" among their campuses.

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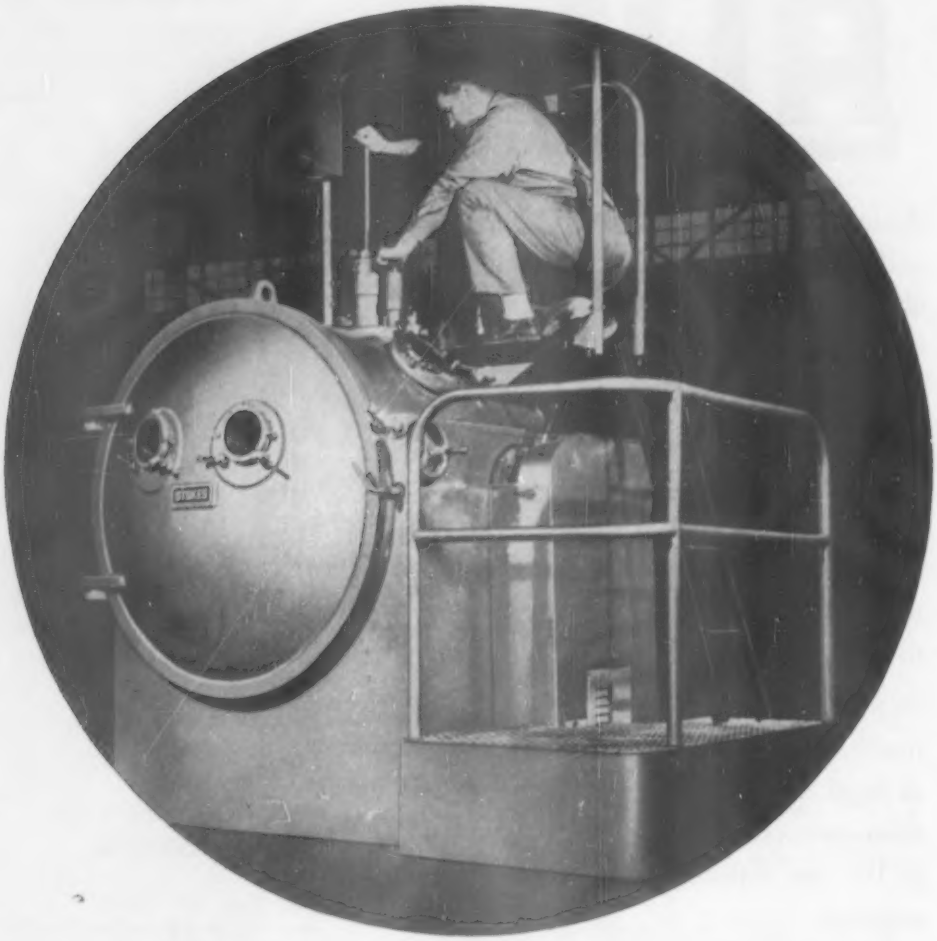
	@ 1 mc.	9.0
	@ 1000 mc	8.6
	@ 10,000 mc	8.4
Dielectric Strength	(volts per mil)	250
Power Factor	@ 60 cy.	0.0005
	@ 1 mc	0.0005
	@ 1,000 mc	0.0006
	@ 10,000 mc	0.0008
Loss Factor	@ 10,000 mc	0.0067
Electrical Resistivity	@ 25°C	10^{16}
	@ 200°C	10^{13}
	@ 400°C	10^{10}
	@ 600°C	10^{8}
	@ 900°C	10^{6}

MECHANICAL

Tensile Strength	26,500 psi
Modulus of Rupture (¼" rod)	48,000 psi
Compressive Strength	285,000 psi
Modulus of Elasticity	43×10^{6}
Specific Gravity	3.62
Density (lbs./cu. in.)	0.131
Water Absorption	0.00
Porosity	Vacuum tight
Hardness (Moh's)	9
Color	White
Working Temperature (Max.)	1600°C
	2912°F
Specific Heat	.19
Coefficient of Thermal Expansion	
(25-200°C)	6.58×10^{-6}
(25-400°C)	7.20×10^{-6}
(25-600°C)	7.65×10^{-6}
(25-800°C)	8.07×10^{-6}
(25-1000°C)	8.45×10^{-6}
Thermal Conductivity	
Btu/hr./sq.ft./°F/in. @ 100°F	130

69E

STOKES ANNOUNCES



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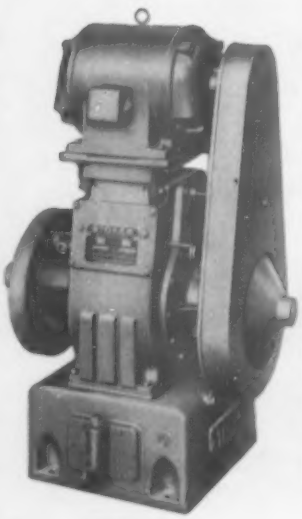

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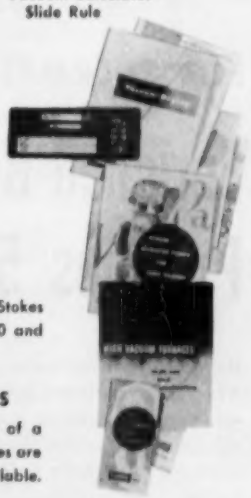
- How to Care for Your Vacuum Pump—Booklet 755
- Vacuum Impregnation—Catalog 760
- Vacuum Drying—Catalog 720
- Vacuum Furnaces—Catalog 790
- Vacuum Metallizing—Catalog 780
- Vacuum Calculator Slide Rule



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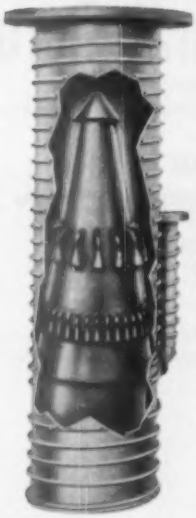

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NUCLEONICS MARCH, 1955

Jerome D. Luntz, *Editor*

Can We Legislate Ourselves into Radiation Safety?

A Guest Editorial by LAURISTON S. TAYLOR, *Chief, Atomic and Radiation Physics Division, National Bureau of Standards; Chairman, National Committee on Radiation Protection*

WITHIN THE PAST FEW YEARS there has been a rapidly growing tendency to legislate on matters of radiation protection at all governmental levels. Is this good or bad? It can probably be either or both. At the Federal level, greater control on matters of health and safety is explicit in many parts of the new Atomic Energy Act. With the greatly expanded public use of atomic energy and its by-products encouraged by this Act, such attention to safety is wise.

On the other hand one can reasonably wonder about the wisdom of radiation control by ordinance at the municipal level. Generally speaking, a municipality can scarcely be expected to provide that degree of technical competence necessary to do much more than verify that a radiation source exists. And too, one should begin to worry when it is found that radiation control may be sought primarily as a source of revenue—through licensing.

The solution to the radiation problem probably lies somewhere between the two extremes mentioned above. Federal control, essential in the atomic energy industry, cannot reasonably be expected to cover the use of X-rays and naturally radioactive sources, which will greatly outnumber artificially radioactive sources for many years to come. If anywhere, the main burden of control will fall to the states, for it is essential that if any control be exercised it cover all radiation sources.

At once we are faced with the possibility of 48 states developing their own independent radiation safety and control regulations. Even worse, there is already limited evidence that more than one agency in a state will establish such regulations. Pity the poor manufacturer of some radiation device, if for sale in a single state, he must make it comply with the requirements of State Health, State Labor, Municipal and Federal codes, all of which may differ slightly in some essential detail.

Radiation is a two-edged sword, but wielded properly can serve mankind—wielded carelessly it can of course harm that same mankind. Radiation legislation can help or hinder. Carefully drawn it can guide and educate and make possible wider uses of radiation. To accomplish this on a national scale, in a country constituted as ours with its multiplicity of governmental steps, it is imperative that all steps operate on the same basic principles.

FORESEEING THIS NEED several years ago the National Committee on Radiation Protection undertook to develop a philosophy and a pattern of radiation regulation that could serve as a guide to the states. For 25 years the NCRP has been recognized as the central source of basic radiation protection philosophy and information in the United States. Close ties with the International Commission on Radiation Protection have insured close agreement with international progress in the field. The subcommittee on the Regulation of Radiation Exposure is just now completing its recommendations, and some of these are already finding their way into proposed state legislation. Through the use of these guides it should be readily within the grasp of any state to establish a radiation control pattern that will provide that essential degree of uniformity necessary to prevent utter chaos in the radiation protection field.

Centralization of radiation control functions should be within a single agency if possible; at the very least a single agency should have the primary cognizance over all radiation protection activities within a state. Advisory committees should be established to insure adequate and continuous technical guidance to state authorities.

Training and certification programs, in addition to those now run by AEC, should be developed at the national or state level to insure a greater supply of reliable radiation safety experts. Let it not be believed that the average steam boiler inspector can be trained in a few days to include radiation inspection in his duties.

Good regulations, properly and uniformly enforced, may well aid in the use of radiation. But they must be reasonable and must not make demands upon the user that will seriously complicate or plain hinder his operations. A rule that would necessitate daily accounting of numerous small quantities of radioisotopes would quickly end in neglect. So then also would some more essential rule. Regulations, however good, if not enforceable, will lead to neglect and abuse, to the development of a false sense of security and to their ultimate disrepute.

TO ANSWER OUR QUESTION. Yes, we can have radiation protection, and legislation can be a real aid in its achievement—but legislation alone can never do it. Let the states beware that they not rush in where experts fear to tread.

Reprocessing REACTOR FUELS

Pulse-column solvent-extraction methods are used for recovering fissionable material from used reactor fuels. Estimated recovery costs for a projected improved solvent-extraction plant help define processing economics and problems involved in cutting costs. Volatility and pyrometallurgy methods, outlined here, hold hope for the future

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IMPROVEMENTS in techniques for reactor-fuel reprocessing, which is widely regarded as a key cost factor, will speed achievement of economical nuclear power. Since most of the fuel remains unconsumed after a given reactor cycle, an examination of how fission products, plutonium, and uranium are separated from spent reactor fuel helps in understanding major problems involved in cutting processing costs.

After being used in a reactor for some optimum time, the fuel is taken out and treated to: (a) remove reactivity-poisoning fission products and recover radiochemicals, (b) recover fissionable materials, (c) remove effects of radiation damage and prepare fuel for reuse by blending it with fresh feed material and reconstituting its structural properties.

In general, difficulties are caused by: (a) remote operation and maintenance of concrete-shielded equipment necessitated by extreme radioactivity of fission products, and (b) problem of efficiently separating uranium and plutonium from fission products and each other. Loss of U and Pu to fission-product waste should be minimized. To handle the processed fissionable fuels directly, without using heavy shielding, product U and Pu must contain less than 1 ppm of the 30-odd fission-product elements.

Possible processing methods for the recovery of reactor fuel materials include: aqueous chemical processing with solvent extraction, volatility methods, pyrometallurgical processing including inorganic extraction, ion-exchange techniques, absorption, and precipitation. Government-owned fuels separations plants use aqueous chemical processing for recovering uranium and plutonium.

Aqueous Chemical Processing

Aqueous chemical processing of reactor fuels consists of: dissolution and U-Pu oxidation, solvent extraction to remove U and Pu from fission-product radiochemicals, separation of U from Pu, stripping of U from solvent to aqueous phase, conversion of aqueous U salts to metals, processing of fission products for specific radiochemicals, recovery of solvent for recycle, recovery of acids from waste solutions, removal of radioactive iodine, xenon, and krypton from waste gases.

Solvent Extraction

The solvent-extraction process, commonly used in the atomic energy program and whose features are shown in Fig. 1, bases separation on the preferential solubilities of fission products, plutonium, and uranium in various counterflowing organic and aqueous

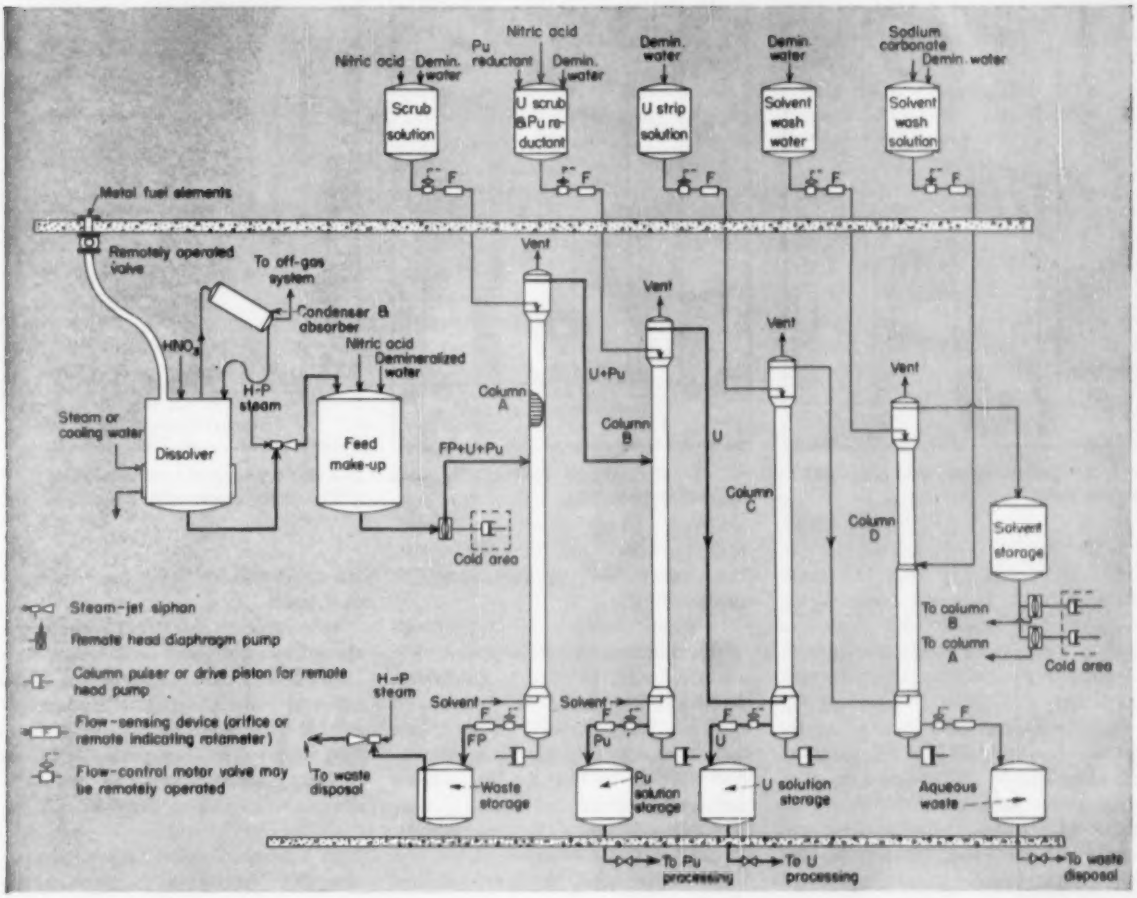

FIG. 1. Typical pulsed solvent-extraction process for separating Pu, U, and fission products. After slug consisting of fission products, Pu, and U (perhaps alloyed with Al) jacketed with Al has been dissolved, solution is jetted to feed makeup tank, where HNO_3 and U-concentration are adjusted. Then fuel-bearing aqueous feed is pumped to extraction column *A*, where rising organic-phase solvent (tributyl phosphate in kerosene) removes U and Pu, and the cladding or alloying materials and fission products in aqueous solution drop from column into storage tanks. Scrub solution removes trace fission products before organic phase with U and Pu collects in upper disengaging section and overflows into column *B*, where falling reductant solution changes Pu's valence state so that Pu goes from organic to aqueous phase and comes out the column's base. Organic phase containing U cascades into column C, where water or very dilute acid (instead of concentrated HNO_3 used in column *A*) strips U into aqueous solution, in which it leaves at base of column C. Organic phase goes to column *D* and, after being scrubbed clean, is stored and pumped back to columns *A* and *B*, where it is reused in the process

solutions. Variations of this process can separate Pu from U, or U from Th, and all of these from fission products.

The process. After fuel elements of a uranium-fueled heterogeneous reactor have been in the reactor the optimum time for burnup and Pu buildup, they are removed and stored so that short-lived fission products decay somewhat and much of the 2.33-day-half-life Np^{239} decays to Pu^{239}. Then they are dissolved in aqueous acid solution. The fuel mixture may contain some structural fuel-element material such as aluminum, chromium, niobium, or zirconium.

The process solutions can be brought into contact in either packed columns, mixer-settlers, or pulse plate columns. An advantage of pulse plate columns is that they can process solutions that contain particulates and solids. Pulse columns also have high separation efficiencies per unit of height.

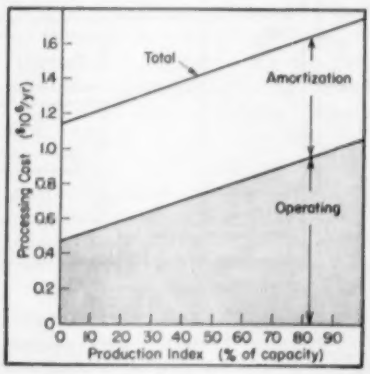

FIG. 2. Annual costs of chemical processing for varying production index

Depending on the materials involved and the products desired, processing of fuels from different types of reactors might involve use of special process cycles that add to, combine, or eliminate some steps described here. Before dissolution, it is desirable to remove residual sodium from the surface of elements from Na-cooled reactors. Homogeneous-reactor aqueous fuels

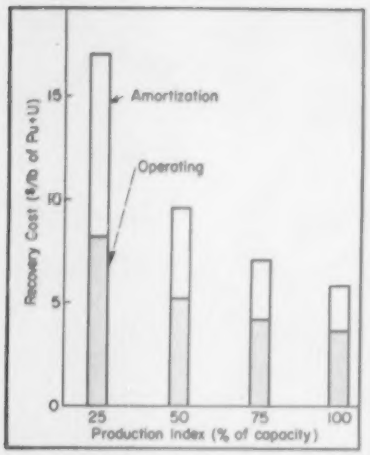

FIG. 3. Cost/lb of Pu + U processed at various rates

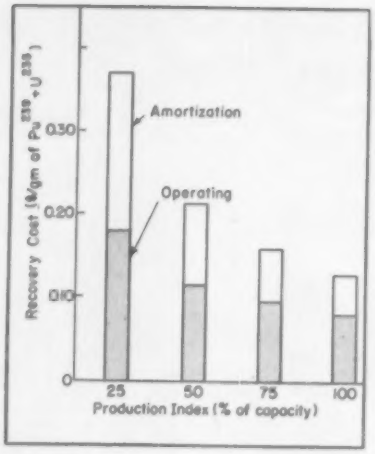

FIG. 4. Cost/gm of $Pu^{239} + U^{235}$ processed at various rates

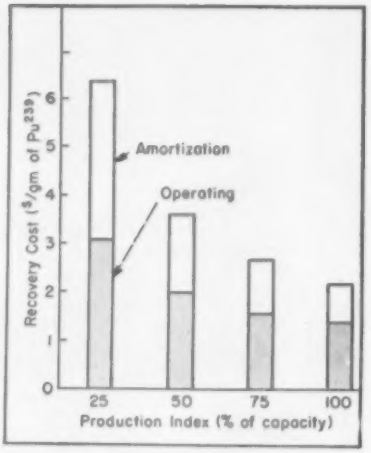

FIG. 5. Cost/gm of total calculated Pu^{239} produced at various rates

skip the dissolution step, but must undergo other processes before being introduced to the solvent-extraction cycle. Fuel from highly-enriched-U reactors might skip the Pu-extraction step, but finally be re-enriched by spiking with enriched material or by partial passage through a gaseous-diffusion plant. Since isotopic concentrations of U and Pu differ in the core and blanket, the extraction systems for breeders might employ parallel steps while using common equipment for chemical preparation, waste disposal, and product metallurgical work.

Pulse columns. Since the usual 6-ft concrete-shield thickness puts a premium on space, the fact that pulsed columns are 2.5–3 times shorter (*2*) than equivalent packed columns gives them a real cost advantage. The process in Fig. 1 uses pulse columns. Reciprocating pistons or bellows pulse the columns' counterflowing liquids so that the surface areas of the drops of the discontinuous organic phase are increased and contact efficiency is improved.

The pulses' best product of amplitude and frequency gives a high-efficiency emulsion separation in which small discontinuous droplets of aqueous or organic phase are dispersed in the other throughout the cycle. Too little pulse activity allows the heavy and light phases to coagulate during the quiescent part of the cycle, and this decreases efficiency. Overly vigorous pulsing forms large globs of the discontinuous phase and disturbs the counterflow; still greater pulsing causes flooding, where a phase exits through the other's entrance line.

To avoid physical entrainment and pre-flooding, care must be exercised in column design to provide for proper introduction of scrub solutions, feed solutions, and solvent. Pulse column diameter must be large enough to prevent flooding at the design capacity, but size is limited by criticality considerations. Design factors include: spacing of the perforated plates, the available free area, and distribution of the discontinuous phase to the continuous phase.

When column diameter is quite large, slotted and baffled redistributor plates (having free area 15%) are used to break up channeling so that the phases swirl into contact and better interaction occurs. In one particular case, suitably placed redistributors cut product loss from a value of 6% to 0.001% (*3*).

In a plant of much higher capacity than the 300,000-lb/yr plant whose

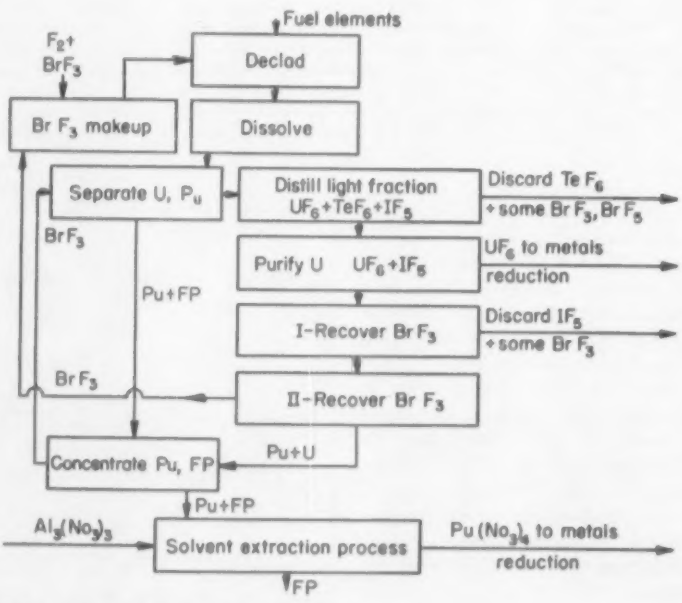

FIG. 6. BrF_3 volatility separations process

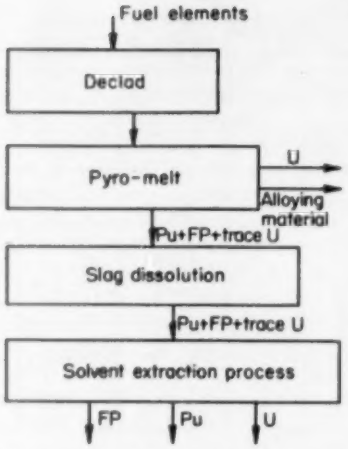

FIG. 7. Pyrometallurgical process for uranium separation and solvent-extraction for plutonium purification

economics are to be considered here, a typical pulse column might be 2 ft in diameter, and use stationary 2-in. spaced horizontal stainless-steel plates with ⅛-in. perforations to give a 23% free area (*3*).

Diethyl ether has been indicated as being a suitable solvent extraction and chelating agent for effectively removing U and Pu from radiochemicals (*4*). Tributyl phosphate dissolved in a kerosene-type hydrocarbon has been said to be a suitable uranium extractant (*3*). Thus, the process fluids might consist of a kerosene-type hydrocarbon with 12.5%-by-volume TBP and 0.18-mole/liter uranyl nitrate in 2.6-mole/liter HNO_3 (*2*).

Continuous flow through the dissolution and feed-makeup steps decreases the need for dual equipment, lessens criticality problems, and permits the entire process to operate continuously, with resultant savings.

The extracted uranium and plutonium solutions are free of radioactive fission products and are routed to metal-reduction operations that prepare them for use as new reactor fuel.

Waste problems. Storage of the radioactive fission products introduces an important cost factor. Economical means for using these products constructively and adequate disposal are being investigated. Presently these wastes are concentrated and stored in underground tanks at Hanford, Oak Ridge, Savannah River, and at the National Reactor Testing Station.

Effective means recently have been developed for selectively separating specific radioisotopes from gross fission products. These methods use ion exchange techniques and selective organic chelation and solvent extraction. Co-precipitation and selective leaching methods also might be used. Improvements have been made in techniques for concentrating aqueous wastes into solid form. Thus, gross fission products in packaged containers soon will be available.

Disposal of the liberated process gases formerly posed a problem. It was necessary to control dispersal of the gases to the atmosphere through tall stacks. After cost data become more firm, processes developed for removing radioactive gases from inert gas streams may make it feasible to process in highly populated areas independently of atmospheric conditions. These new processes effectively separate the radioactive iodine, xenon, and krypton from waste gases prior to release to the atmosphere. Incidentally, this makes an excellent source of Kr^{85} for sale.

Solvent-Extraction Costs

Investment, operation, and product costs have been estimated for a future processing plant located adjacent to a reactor facility (*1*). It is assumed that the three-cell plant would have a Pu and U processing capacity of 300,000 lb/yr—which would be adequate for four 500-Mw breeder reactors. The first cell would be used for solvent extraction, the second for converting U and Pu to metals for recycling, and the third cell would serve as an intermediate storage area for radiochemicals.

After a preliminary expenditure of several million dollars for industrial research and development, capital investment might be about $6-million. The cost estimates do not include allowances for research and development, metallurgical fabrication, or fuel-inventory charges, which might be substantial. Plant amortization estimates include obsolescence. Operating costs include chemicals, payroll, utilities, maintenance, and supplies.

Annual production costs. Figure 2 shows the estimated production costs. For a single 500-Mw breeder, these would be $1.27-million/yr. At full capacity (processing for four such reactors), cost would be $1.74-million/yr.

Cost/lb of Pu + U. Figure 3 shows how unit costs would be affected by throughput. The $17/lb cost at 25% capacity could be reduced to $5.80/lb by operating the plant at its full capacity.

Cost/gm of $Pu^{239} + U^{235}$. Effect of charging processing costs to recovery of U^{235} and Pu^{239} is shown in Fig. 4. The $0.37/gm cost at 25% capacity could be reduced to $0.13/gm at full capacity, where 13,640 kg of $Pu^{239} + U^{235}$ would be recovered per year.

Cost/gm of Pu^{239}. If plutonium would be considered as the product to be sold and U^{235} could be reused as zero-cost fuel, then Fig. 5 shows how all costs of fuel recovery and processing would be applied to the unit costs of the total calculated Pu produced at various plant throughputs. The $6.37/gm cost for Pu from one reactor could be cut to $2.16/gm if Pu from four reactors were processed, in which case 800 kg of Pu would be produced annually.

Other Separation Methods

Many other processes could be used for recovering reactor fuels. Chief among these are the volatility and pyrometallurgy techniques.

Volatility. The BrF_3 volatility method shown in Fig. 6 might be used to purify U in conjunction with a solvent-extraction system for decontaminating the Pu. Both core and blanket materials might be treated in the same equipment in some of the steps, but their dissimilarity would prompt use of parallel equipment (not shown) for most of the operations (*1*).

Pyrometallurgy. Figure 7 shows an extrapolated process for recovering U by using pyrometallurgical techniques with subsequent solvent extraction for Pu purification. The method would keep most of the U in its original physical and chemical state. There would be some parallel steps for treating blanket and core materials. If slagging techniques are developed that permit selective pyrometallurgical extraction of U and Pu without excessive losses in the slag, use might be made of a simplified process in which solvent extraction is eliminated.

Improved techniques and refinements in existing methods will do much to hasten economical nuclear power.

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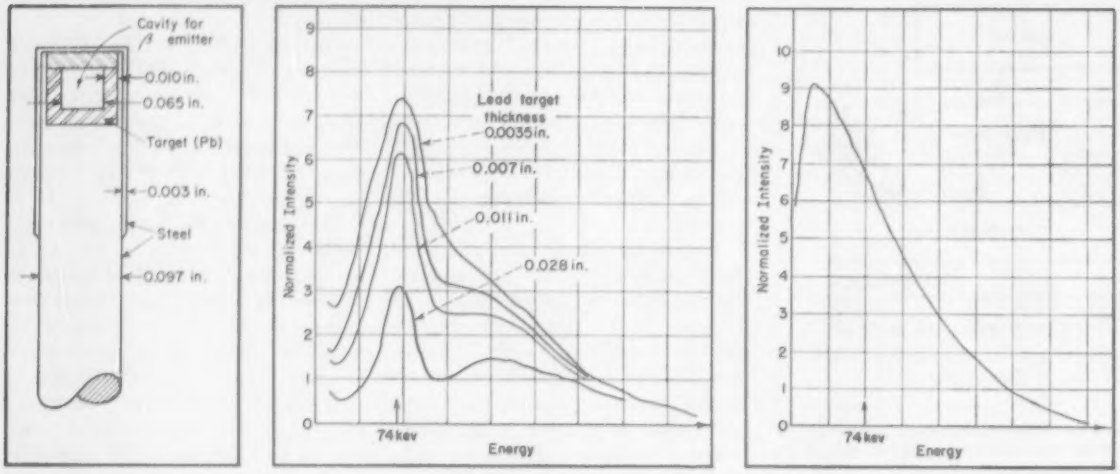
2. G. Sege, F. W. Woodfield, *Chem. Eng. Progr. Symposium Ser. No. 13*, **50**, 179 (1954)
3. Ref. 2, p. 14
4. F. R. Bruce, AECD-3449 (1952)

1—TRANSMISSION-TARGET SOURCE



Transmission-target source, with Sr^{90}-Y^{90} betas, gives spectra in center for various target thicknesses and at right for bremsstrahlung

Beta-Ray-Excited Low-Energy X-Ray Sources

Beta-ray excitation provides X-rays in the range below 400 kev where gamma emitters are lacking. Although present units only yield up to 1/10 mc of X-rays per mc of beta particles, their portability and stability recommend them for radiography, thickness determinations, and X-ray fluorescence analysis

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PROMPTED BY THE LACK of low-energy (<400 kev) gamma-emitting nuclides, for several years we have been exploring the possibility of using beta-ray-excited X-ray sources. Such sources are constructed using pure beta-ray emitters to bombard target nuclei much in the same fashion that electrons in an X-ray tube bombard the anode; the two processes are essentially identical in the physics involved. Although radioactive sources cannot compete with electronic X-ray sources where very high intensity is required, their zero power consumption, small size and portability, long-time stability, and other advantages would be of value in many applications.

Using Sr^{90}-Y^{90} beta emission, we have demonstrated the practicality of such sources. This article discusses the characteristics of various source designs and the possibilities for future development.

These sources are needed because of the small number of low-energy-emission radioisotopes in the classical X-ray region. Among the few useful emitters in this region are thulium and iron-55. Thulium, which emits 84-kev and 52-kev radiation, is available at high specific activity but, unfortunately, has an inconveniently short half-life of 129 days. It has been developed for radiography* and absorptiometry. Iron-55 emits, by *K*-capture, a 6-kev X-ray. It has a conveniently long life—2.9 years—but its energy is unfortunately somewhat

* S. Untermyer, NUCLEONICS **12**, No. 5, 35 (1954).

low for many purposes. It has found limited application in exciting fluorescence X-ray spectra from the lighter elements. A considerable gap exists, therefore, in available energies.

Fortunately there is a rather wide choice of pure beta-ray emitters, ranging from the strontium-90-yttrium-90 chain, emitting 0.6-Mev and 2.2-Mev betas with an effective half-life of 20 years, down to materials such as phosphorus-32 with a 1.7-Mev beta and a 14-day half-life or calcium-45 with a 0.25-Mev beta and 152-day half-life. In all, there are approximately ten beta emitters useful for the production of X-rays by the methods to be described.

Mechanisms

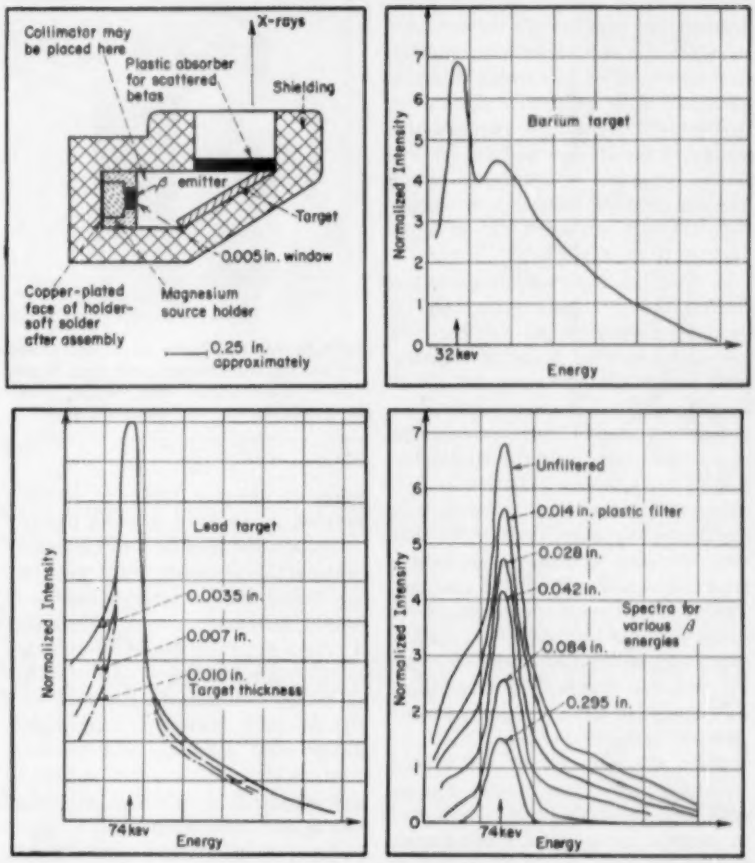
Two mechanisms are active in producing X-radiation when the betas from such isotopes are allowed to interact with target nuclei. The first involves simple acceleration of charge during the beta absorption process and results in bremsstrahlung radiation. The second radiation source is principally the result of ionization in the K shell of target atoms with subsequent emission of characteristic or K-radiation. Characteristic radiation may be excited directly in an interaction between a beta particle and a target atom or indirectly when the target atom absorbs bremsstrahlung radiation formed elsewhere in the target material.

For thin targets, the efficiency of bremsstrahlung production is proportional to the square of the atomic number of the target material and to the first power of the beta-ray energy. For energies of the order of the P^{32} beta and for a lead target, quantum efficiencies of the order of 10% have been measured when only X-rays in excess of 50 kev are considered. The effectiveness of such a mechanism therefore compares reasonably well with the branching ratio in the decay schemes of materials such as thulium. The efficiency of direct excitation of fluorescence radiation by beta bombardment had not been studied in detail. It is complicated by indirect excitation previously mentioned. This aspect of the performance of the sources is undergoing further measurement.

Source Design

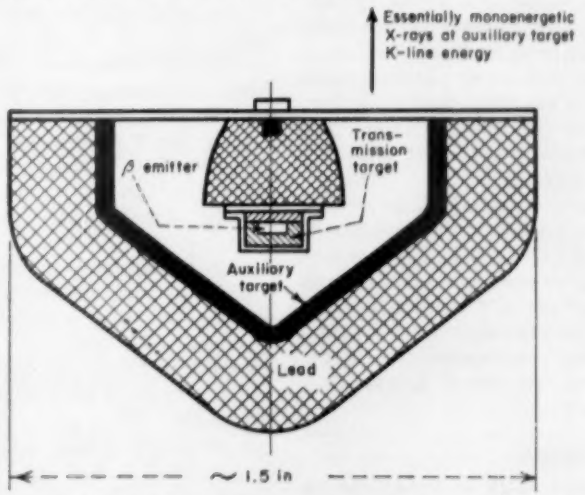
Various configurations can be used for beta-ray excited X-ray sources. Among others, liquids can be mixed

2—REFLECTION-TARGET SOURCE



Reflection-target source, with Sr^{90}-Y^{90} betas, provides spectra at bottom left for various thicknesses of lead target and top right for barium target; spectra for various beta energies, bottom right, were obtained with lead target, plastic filters, and Sr^{90}-Y^{90} source

3—MONOENERGETIC X-RAY SOURCE



Source provides almost completely monoenergetic radiation with energy dependent only upon auxiliary target material

with the beta emitter material, or solid powders can be intermixed much in the manner that neutron sources are constructed, or a core of beta-ray emitter can be surrounded by a casing of target material. Still another configuration that lends itself readily to changing the energy of the X-rays emitted by the source employs a reflection target wherein the beta emitter is separated from a target surface in almost direct analogy to an X-ray tube.

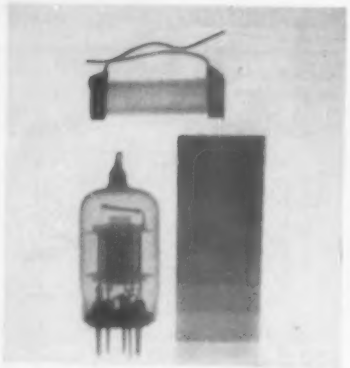
A typical X-ray transmission target (casing target) configuration and a typical reflection target configuration are shown in Figs. 1 and 2, together with spectra obtained using Sr^{90}-Y^{90} as the beta emitter. Various target thicknesses were used to illustrate the effect of conversion of bremsstrahlung radiation to characteristic radiation in each case. The curves are all normalized to the same peak intensity, and the data were obtained with the usual sweep-type differential-pulse-height analyzer. The measured energy spectrum is of course smeared by the finite resolution of the sodium-iodide scintillation-counter detector. The actual spectrum would exhibit a very sharp spike at 73.8 kev in the case of lead.

Since the intensity of the bremsstrahlung continuum varies rapidly with beta-ray energy, it is evident that to secure monoenergetic X-ray sources low-energy betas should be employed. Figure 2 displays the result of filtering the betas from Sr^{90}-Y^{90} through various thicknesses of Lucite. It is noteworthy that the ratio of the *K*-line intensity to the continuum increases with decreasing beta-ray energy; also the integrated intensity decreases with decreasing energy. The bottom curve of this series shows the lead fluorescence excited by the bremsstrahlung present due to the beta source structure itself and demonstrates another interesting source configuration.

To obtain a source of monoenergetic radiation, the wavelength of which may be varied over wide limits, it is only necessary to provide a source such as illustrated in Fig. 1 with a second target so positioned that it can be bombarded by the X-radiation from the source. A typical configuration is shown in Fig. 3.

Applications

The wide range of energy spectra available from the several source designs, in combination with the wide range of effective half-lives, opens a number of areas of possible utility.*



TYPICAL RADIOGRAPH using 10-mc Sr^{90}-Y^{90} source, lead target, and type K film; objects are aluminum step wedge (0.050-in. steps), resistor, and electronic tube

The sources may be used for radiography of thin sections or light materials. For radiography, it appears feasible to obtain carrier-free activity such that 1 curie of strontium can be incorporated in a 1.5-mm focal spot. For emitters of shorter half-life, the specific activities would be correspondingly higher. Fairly good definition and comparatively short exposure times will be possible with a full-scale strontium source now under construction. Radiographs of full density should be obtainable through ½ in. of aluminum at 4-min exposure times and source-to-film distances of about 1 ft using type K film. Intensification screens and faster films would reduce exposures correspondingly. The sources alone are not sufficiently intense for medical radiography, but it appears entirely possible that compact image intensifiers (either electronic or solid-state types) may be used to advantage, thereby making such applications feasible. The possibility of placing the source within the object to be radiographed may be advantageous. The possible utility of the sources in medical therapy has not been examined.

Either the continuous spectrum from a source emitting primarily bremsstrahlung or a line-spectrum source of known properties may be used in thickness gaging over a fairly wide range of thicknesses. There appear to be certain advantages in using X-ray sources in preference to beta-ray sources in some gaging applications, but this aspect of the problem needs further exploration. The continuous spectrum is ideally suited to density measurements in liquids, gas-liquid mixtures, and slurries. High-speed density determinations to better than 1% accuracy have been achieved with automatic instrumentation.

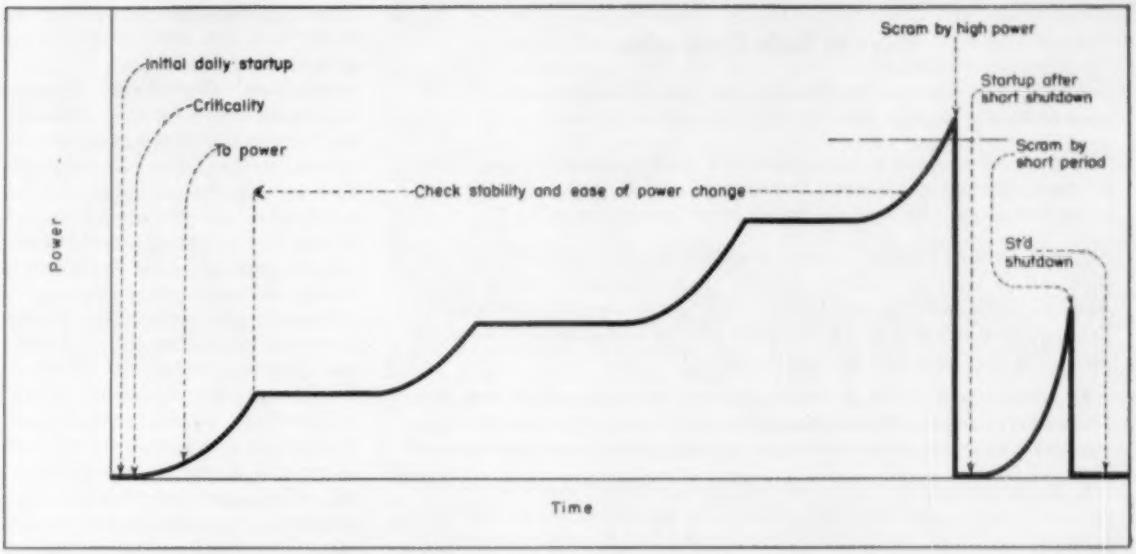
The line spectra obtainable from these sources are admirably suited to absorptiometry, particularly for coating control or for additive concentration control, as well as for chemical analysis. The energy of the incoming radiation may be set at the critical absorption edge of the element of interest and thus render the system preferentially sensitive to variations in this element. Such a technique appears promising, for example, in silver-emulsion thickness control where antimony radiation may be used to probe silver content of the emulsion as it is deposited without producing sufficient exposure to fog the film.

With either the X-rays from such sources or beta rays directly, X-ray fluorescence analysis in certain simple systems can be achieved. Here the low intensity of the sources, compared to X-ray machines, may be at least partially compensated for by the use of Ross balanced-filter techniques to obtain large effective apertures and still retain the required energy selection properties of the detector.

In most of the applications examined, with the exception of radiography, the sources have employed millicurie amounts of beta emitter to achieve adequate counting rates in the detectors, which are usually scintillation counters exhibiting close to 100% efficiency in the energy range of interest. The yield per millicurie of beta emitter will, of course, vary with the details of the source configuration. For a typical transmission-target design, a nominal value of $\frac{1}{10}$ mc of X-rays per millicurie of beta particles may be used to estimate the required activities. For reflection targets, this figure must be reduced by about one order of magnitude, i.e., 10 μc/mc. These rough figures apply to bremsstrahlung spectra for emitters such as P^{32} and Y^{90}. The ratio of bremsstrahlung to fluorescence radiation may be estimated from the curves previously discussed.

Further details of developments using the techniques sketched here will be reported at a future time.

* Patents have been applied for on various phases of this work.



EIGHT STEPS are involved in the operating tests

AEC Inspects Reactors for Safety

To maintain safe reactor operation, all U. S. industrial and university reactors are being inspected by AEC. The inspection tests verify adequacy of the operating organization, procedures, and equipment. Recommendations based on tests made to date help reactor designers and operators plan safe operation

For information on which this report is based, NUCLEONICS is grateful to Richard H. Graham, Division of Reactor Development, U. S. Atomic Energy Commission, Washington, D. C.

ALTHOUGH IT hasn't been publicized, the Atomic Energy Commission has begun a standardized reactor safety inspection program. This program, which has been developed during the past year, may serve as the basis for AEC's future inspections. All university and industrial reactors will be inspected under the arrangement that now involves mostly AEC research reactors.

The tests, which regulations under the new Act make mandatory for operation of most off-AEC-site reactors, are conducted in a way that acquaints operators with the best equipment and latest safety techniques. It gives them the benefit of a perspective against which they can judge and improve their procedures.

The AEC and Safety

The Commission is charged by Congress with general responsibility for seeing that reactors, critical facilities, exponential assemblies, and other such nuclear devices do not endanger the health and safety of the public. The new standardized inspections and the established general safety reviews by AEC's Advisory Committee on Reactor Safeguards (ACRS) help the Atomic Energy Commission fulfill this obligation.

Review. A preliminary design of a reactor that is safely operable is evolved from early-stage meetings of the designer and ACRS. When design is complete, this committee again reviews layout details and operating plans. If the Committee's report to AEC's General Manager is favorable, he usually directs the responsible division and its operations office to issue reactor fuel and a formal certificate of permission to operate the reactor with whatever restrictions and modifications the ACRS recommends. The same review procedure is followed

Keys to Safe Operation

As a result of inspection experience to date, general recommendations can be made concerning reactor operation. There should be:

1. *A reactor operating group separate from any experimental group. This full-time operating group should be concerned with the safety of the reactor rather than the completion of any specific experiment or program.*

2. *A formalized training program to assure operator familiarity with the plant. High levels of academic training are not necessary; use of college graduates on the operating consoles of routine reactors is a waste of manpower. The operator should be a skilled technician who has been educated to the point where he is thoroughly familiar with the plant.*

3. *A well-defined operating organization with clear cut levels of authority. These should be thoroughly described so that there is no confusion in the operating group as to who has authority to modify any procedures or equipment.*

4. *A very complete written standard operating procedure describing routine methods of startup, operation, and shutdown. It should state who is authorized to operate the reactor, to modify the reactor, and how to handle experiments involving modifications to the reactor. In many cases deviations from standard operating practices are required, but it should be stated that if deviations from these carefully thought out and tested procedures are necessary, they must be reviewed with specified staff members competent to judge safety. Use of check lists is often recommended.*

5. *An independent health-physics organization making and posting frequent radiation surveys, developing such things as health-physics procedures for hazardous and unusual operations, and advising the operating organization in formulating procedures. Where organizationally possible, the health-physics crew should have a separate channel outside the operating organization to management so that differences of opinion can be settled on a conservative level. This isn't easy in a university group, but it certainly should be a part of an industrial setup.*

6. *Adequate instrumentation consisting of: (a) a source interlock; (b) detector or neutron-information channel that sees the source before startup so initial phases of startup are not done blind; (c) an audible counting-rate meter for use during startup—the actual clicking of the register on a scaler is a very informative piece of information to a man who is trying to watch one or more dials and do a number of things at once; (d) two power-level channels, and one period channel, all three set to scram the reactor at a rather conservative level; (e) since much can be gained from simplicity in the control instrumentation, nothing should be included that isn't really necessary; and (f) experimental data being derived from the reactor should be collected at a position isolated from the control console so as not to confuse the operator.*

7. *Procedures for frequently testing all safety devices by response to the reactor's kinetics. Although it is valuable to test a power-level-channel scram function by inserting an electric signal to simulate the given power level, this is a very poor substitute for raising the power level of the reactor to see that the overall system operates to make the rods drop and make the reactor subcritical. If the power-level scram is set so high that operating people are reluctant to take the reactor into that region, then it is set too high to begin with. A weekly test is advisable.*

8. *There should be more than one power-level circuit operative at a given power level. And, although there are differing opinions on this, instead of standardizing on a favorite detector at a specific facility, it might be worth while to use several different types. The perfect neutron detector doesn't exist. While identical instruments might supply the operator with the same data, they might neglect some part of the phenomena.*

whenever the operator wants to use the reactor in any manner not spelled out in the original certificate.

Inspection. Shortly after the reactor begins to be operated routinely, AEC notifies the operating organization of a date set for a safety inspection that is to be made to: (a) insure that the certificate's provisions are adhered to, (b) see that operating procedures are adequate, and (c) advise the operators of improved techniques and equipment.

Presently, the inspections involve mostly on-site facilities and the few off-site research reactors, but all future U. S. industrial or university reactors will undergo similar examinations. Presently, the inspections are set up to be run once a year by personnel from AEC-Washington, but consideration is being given to having the nearest AEC operations office perform the task at intervening periods. Production reactors, military reactors, and specialized weapons-test facilities are allied to defense requirements, and thus are inspected under a different arrangement.

The Inspection

Each inspection has taken the inspector about two weeks' preparatory study of design and operating procedures. About half a day is spent discussing procedures, policies, and organization with operating supervisors. Roughly four hours are devoted to operating tests. These consist of having the regular operating technicians perform certain functions.

Although differences in design power level and operating flexibility require procedural variations for different reactors, a standardized program is followed. This program requires that the inspector: (a) review reactor construction, operating procedures, uses, staff organization, and division of authority; (b), have the staff perform reactor operating tests; (c) review operating log and standard operating procedures; (d) discuss with staff the comments and recommendations planned; (e) submit report to Director of Reactor Development.

Review construction, uses, staff. The reactor's construction features are discussed to insure that inspection personnel understand how the particular reactor works and to learn of any modifications since certification or previous inspection. The specific experimental program is reviewed to learn of any core-configuration changes or insertions

or removals of materials that affect reactivity.

Staff organization and division of authority is considered to see who makes decisions to break routine operating procedures and to make sure that the routine operators and experimenters have a clear picture of what they can do without asking senior people to approve. The inspector wants to see how and by whom new experiments or reactor alterations are proposed, reviewed, and decided from the standpoint of safety. Most facilities have a committee or individual responsible for making these reviews and decisions.

Perform operating tests. This is the key phase of the inspection. Startup on standard daily procedure is made to learn: (a) how thoroughly the operator checks the reactor before startup; (b) how smoothly the startup actually goes; (c) if the operator has too many things to do at once; and (d) if startup is a fairly straightforward operation.

The reactor is operated at various power levels so as to get a feel for how stable the reactor is—does it handle like a hot-rod, or does it sit on a given power without much attention? Less desirable reactors require constant attention and control by an operator. Most reactors are very stable; after getting to a given power, there's not much to do to keep them at that power —except perhaps to compensate for temperature and xenon until they come into equilibrium.

The inspector also wants to see how easy it is to change power and to learn if awkward range or detector changes have to be made on many instruments during the change in power. A scram shutdown due to excess power level is made to test actual operation of the power-level trip—probably the most important safety instrument. Then a startup is made according to standard procedure to see if the operator checks everything according to the routine checklist before startup after a short-term shutdown.

Then the reactor is made to scram by short period to test the period trip. It is started again, shut down by standard procedures, and shut off in good order.

Additional steps are made to test as many safety circuits as possible. If there are detectors for stack-gas radioactivity, they are checked. All primary safety features, rod action, and scrams for high temperature and low coolant flow are tested. It is better to check the scram devices under actual, rather than simulated, operating conditions. Sometimes this can't be done, but it should be where possible.

If practical, the temperature coefficient of reactivity is determined. Although this measurement generally is difficult and sometimes impossible to make for critical assemblies, it is important to have it, whenever possible, because of concern whether changing core configurations causes a positive temperature coefficient. If a reactor must have a positive rather than a negative coefficient, additional safety devices usually are needed.

Review procedures. The operating log and standard operating procedures are discussed with the staff to emphasize the importance of formalizing procedures, preferably in check-list form.

Discuss recommendations with staff. The chronological report on operating procedure and comments are discussed informally with the operating staff to make sure the report is factual. Recommendations are considered to see that they appear reasonable to all concerned. The staff generally makes useful suggestions during such discussions.

Submit report. The report submitted to AEC's Director of Reactor Development for appropriate transmittal contains descriptions of: (a) the operating organization, (b) general local operating procedures, (c) the operating tests and any variation from expected performance, and (d) comments of the staff and their answers to questions. Recommendations are made concerning procedures that should be brought to the operator's attention. Comments are made on observed procedures and equipment that appropriately could be suggested for use at other sites.

Often a new instrument or circuit that appears to be good has been installed. This is pointed out to other operating groups. As an example, on some reactors the period circuit is arranged so that when the period starts to become too short the control rod reverses direction and starts in, not actually scramming the reactor. But if the period becomes still shorter the rods are caused to scram the reactor. In other cases, a short period or other potentially hazardous condition causes an alarm signal to be given before it reaches the stage where a scram is necessary.

If the report pertains to a research reactor, it is sent to AEC's Research Division. The manager of the Commission's operations office that has jurisdiction over the reactor sometimes will discuss the report with the reactor manager, who reports what he is going to do about the recommendations.

The reactor inspector has limited his activities with regard to health physics to seeing that an operating health physics organization does exist to protect the reactor staff. AEC's Division of Biology and Medicine is responsible for administering this phase of the organization.

Since the Commission is obligated to inspect off-site facilities for security and accountability as well as for safety, inspection teams might be formed in the future to inspect all these factors at one time, thus interfering as little as possible with normal functions of the facility. —END

Reactors Inspected

Since June 1954, 17 reactors have been inspected. AEC has identified the following nine:

- *Raleigh Research Reactor, North Carolina State College, Raleigh, N. C.*
- *SUPO, Los Alamos National Laboratory, Los Alamos, N. M.*
- *Water Boiler Neutron Source, North American Aviation Corp., Downey, Calif.*
- *Livermore Research Reactor, University of California Radiation Lab., Livermore, Calif.*
- *Experimental Breeder Reactor, Argonne National Lab., Idaho Falls, Idaho.*
- *Materials Testing Reactor, Phillips Petroleum Co., Idaho Falls, Idaho.*
- *Submarine Thermal Reactor Prototype, Westinghouse Atomic Power Div., Idaho Falls, Idaho.*
- *Brookhaven Reactor, Brookhaven National Laboratory, Upton, N. Y.*
- *CP-5 Reactor, Argonne National Laboratory, Lemont, Ill.*

Oak Ridge Graphite Reactor and Bulk Shielding Reactor, both at Oak Ridge National Laboratory, will be inspected soon.

FIG. 1. Grazing-incidence-type target is used for cyclotron bombardment when target material can be applied as surface coating. Coating shown is 15-mil electroplated nickel. Cooling water flows through target at 30 gal/min (20 ft/sec). Power dissipation of 66 kw has been obtained. Target size is 6 × 10 in. Target base is silver-plated 2S aluminum

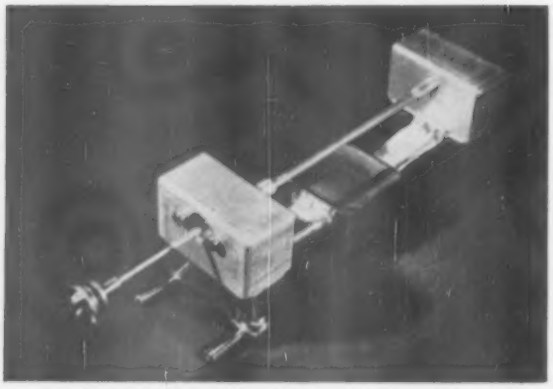


FIG. 2. Capsule-type target is used when material cannot be surface applied. Partially withdrawn tubular capsule, 200-mil outside diameter, is surrounded by jacket. Both are made of 10-mil seamless aluminum tubing. Cooling water at 140 psi flows in 15-mil annulus between capsule and jacket. Tubing walls and water layer reduce proton energy to about 15 Mev. Target currents of 200 microamp are routinely used

Radioisotope Production Rates in a 22-Mev Cyclotron

For both reactor-made and high-yield cyclotron-made radioisotopes, irradiation costs are small compared to decay losses and processing costs. Thus, the cyclotron can complement the reactor by making additional isotopes available at reasonable costs. Here are actual yields for 14 radioisotopes and estimates for 136 others, made in the ORNL 86-inch cyclotron

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A WIDESPREAD BELIEF EXISTS at present that isotopes produced in accelerators are hopelessly expensive when compared with those available from reactors. This is not true. When yields for isotopes produced in the 86-in. cyclotron are reviewed, as in this article, it is found that in a large number of cases irradiation cost for cyclotron-produced isotopes is, as is the case with most reactor-produced isotopes, rather small when compared with the costs assigned to decay losses and to processing and shipping.

Through the period 1930–1945, most radioisotopes used were produced in cyclotrons. Development of high-energy accelerators in the early 1930's had provided, for the first time, a means for producing a wide variety of radioisotopes. Radioactivity was used on an expanding scale in fundamental investigations in many classical fields of science, including physics, biology, medicine, agriculture, and engineering. Nearly all elements then known were subjected to bombardment with protons, deuterons, and alpha particles, and hundreds of new radioactive species were cataloged.

With the advent of nuclear reactors, a new means for producing radioisotopes became predominant. Many widely used radioisotopes, such as C^{14}, P^{32}, Ca^{45}, and Co^{60} could then be produced more economically in reactors.

* Operated by Carbide and Carbon Chemicals Co. for the U. S. Atomic Energy Commission.

Development of "hot" facilities made possible the isolation of fission-product isotopes, such as Ce^{137} and I^{131}. These developments gave additional impetus to research with radioactive tracers. Isotopes produced by neutron capture or from fission could be generated in much larger quantities than those obtained from accelerators. Thus, with the successful development of reactor-produced and fission-produced isotopes, the use of accelerators for radioisotope production was largely neglected.

Until 1949, most emphasis in the cyclotron field had been placed on fundamental studies of very-high-energy reactions, rather than on large-quantity radioisotope production. In 1949, plans were developed at ORNL for a high-current high-energy proton cyclotron that could produce isotopes in quantities previously considered impracticable. In 1950, the machine was put in operation at proton currents that eventually reached several milliamperes. Target assemblies that provide for irradiation of target elements at 10–50 kw were designed and operated.

Cyclotron-Made Isotopes

For producing radioisotopes, the cyclotron largely complements rather than competes with the nuclear reactor. In tracer and therapeutic work isotope characteristics are of greatest importance. Their chemical and radiation properties, and their specific activity determine, to a large extent, the success of a given project.

Cyclotron-produced isotopes usually lie on the neutron-deficient side of the nuclear stability line; they decay principally by electron capture and positron emission, although some undergo beta decay and a few may decay either way. In contrast, nuclei formed by neutron capture or as fission products usually have a neutron excess and decay by negatron emission.

Cyclotron-produced radioisotopes have, in general, high specific activity. They are ordinarily of a different chemical element than the target and hence can be separated with high specific activity, frequently carrier-free. (All atoms of the element are atoms of the radioisotope.) Reactor-produced radioisotopes are usually made as a mixture containing rather large amounts of the stable isotopes of the same element. Exceptions to this are daughter activities, fission products, and (n,α)- and (n,p)-produced isotopes.

Before results of preliminary production tests for 14 radioisotopes and estimates of production rate for 136 others are given, the cyclotron construction will be explained.

The 86-Inch Cyclotron

The ORNL 86-in. cyclotron is novel in that it is a "vertical" cyclotron, the dees hanging suspended from above (*1*). In other respects it is a rather conventional fixed-frequency machine, except that many of its components are of greater capacity than has been customary. Three 20-in. oil diffusion pumps provide high pumping speed, moving 15,000 liters/sec at the operating pressure of 0.03 micron. A self-excited oscillator, yielding in excess of 200 kw r-f power, provides very high dee voltage, 400–500 kv dee-to-dee. The cyclotron operates at 9,000 oersteds and at 13.4 Mc/sec. It has 8-in.-wide dees and 4-in. dee-to-dee and dee-to-ground spacing. The cyclotron operates stably at 1–1.5 ma current.

Target removal. An unusual problem with this type cyclotron is removing intensely radioactive targets from the vacuum chamber. To do this safely, a mechanical manipulator is operated from behind a 4-ft concrete shield pierced with a liquid-filled viewing window. The target-mounting assembly is permanently attached to a carriage that has hydraulic cylinders. The cylinders position the assembly against vacuum seal of target vacuum lock. A screw mechanism advances the target to the proper cyclotron position and withdraws it at bombardment's end. Controls for this carriage are mounted behind the shield wall, as are all other controls for remote target manipulation. The target is removed from the carriage by a mechanism fixed to the lid of a lead transfer box. Transfer box then is placed in a heavily shielded enclosure until target removal for shipment or processing is safe. Targets containing hundreds of curies of high-energy gamma activity can be safely removed from machine to shielded enclosure, but shipment size is temporarily limited to much smaller quantities that can safely be transferred by hand tongs to a shipping container.

Target construction. Operating at 1-ma proton current requires that 22 kw be dissipated by the water-cooled target. Surface temperatures must be held below target-material melting or vaporization point. The grazing incidence principle is used to reduce heat flux to a manageable level.

The beam, whose radial width is $\frac{3}{16}$ in., is spread along a target placed at a small angle to the beam path. Both 10-in. and 14-in. targets have been used successfully. Figure 1 shows a typical target.

The element to be bombarded is coated on the surface in 0.010–0.020 in. thickness. Coating is done in several ways: by casting in a shallow recess in target surface and then machining to uniform thickness; by electroplating; by brazing a foil to target surface; and by using a metallizing gun. In Table 1 on this page, target metals successfully used are listed.

Some elements are not amenable to

TABLE 1—Yields for Cyclotron-Produced Isotopes

Product isotope	*Half-life*§	*Produced from*	*Target used (6 × 10 in. grazing type)*	*Production rates*	
				(mc/ma-hr)	*(mc/hr)*
Be^{7}	54d	*p,n*	Li	170	120
F^{18}	1.87h	*p,pn*; *p,2n*	NaF*	7,500	1,500
Na^{22}	2.6y	*p,α*; *p,αn*	Mg	0.4	0.4
Na^{22}†	2.6y	*p,pn*; *p,2n*	Na	3.1	1.3
Mn^{52}	6.0d	*p,n*; *p,2n*	Cr	80	80
Mn^{54}	310d	*p,n*	Cr	0.5	0.5
Mn^{54}†	310d	*p,pn*	Mn	20	20
Fe^{55}	2.9y	*p,n*	Mn	10	10
Co^{56}	80d	*p,n*	Fe	70	70‡
Co^{57}	270d	*p,pn*; *p,2n*; *p,2p*	Ni	50	50
Zn^{65}	250d	*p,n*	Cu	9.3	9.3‡
Ga^{67}	78h	*p,2n*; *p,n*	Zn¶	600	120¶
As^{73}	76d	*p,n*; *p,2n*	Ge*	8	1.6
As^{74}	17.5d	*p,n*	Ge*	50	10
Y^{88}	105d	*p,n*	SrO*	20	4
Po^{208}	2.93y	*p,2n*	Bi	9.8	9.8

* Capsule-type target is used.

† Isotope produced is not carrier-free.

‡ These data are based on a single run. It is believed that yield can be materially improved with further operating experience.

¶ Target size is 2.5 × 6 in. Production rate of 600 millicurie/hr could be expected with the larger target.

§ See Table 2 footnote on half-life.

these techniques; others, even though they may be applied, may not allow heat-transfer rates high enough to dissipate the large beam power, even with the large grazing-incidence type targets used. Maximum heat flux on the most heavily bombarded area of the target is estimated as 1.5×10^6 BTU/hr/ft^2.

Nonmetals, such as the halogens, must be bombarded as chemical compounds. Generally a thin-walled water-cooled capsule like that shown in Fig. 2 is used. This technique also may be necessary for metals with very low melting points, such as potassium and rubidium. Other elements not readily available in metallic form are bombarded as chemical compounds in this capsule target. In general, somewhat lower bombardment efficiency results. Operation at currents less than 1 ma is necessary because of heat dissipation problems.

When production of a carrier-free isotope is desired, a further requirement must be met. The target initially must be free of the element being produced. While it is not difficult to get the common elements with adequate purity, purity can become a serious problem for some elements such as the rare earths.

If there is sufficient demand for a certain isotope, development work can be undertaken to provide an efficient high-current target. When only millicurie quantities of a particular isotope are desired, development of a high-current target is usually not warranted. For these small quantities, initial production rate may, therefore, be substantially lower than that given in the accompanying tables. Table 1 shows actual production rates for 14 radioisotopes, and Table 2 gives estimated yields for 136 others.

Actual Production Rates

Some 20 elements have been bombarded in the 86-in. cyclotron during the past two years. Millicurie to curie quantities of radioisotopes were produced. Serious efforts were made to obtain the highest production rates possible in view of individual target-fabrication problems. But the capsule target was used in some instances because developing a coating method for the large target would have required much additional work.

Fourteen isotopes were selected for the initial investigation because of their suitability for medical, biological, or industrial uses. Bombardment results, giving preliminary data, are summarized in Table 1, page 29. Actual production rates, in millicuries per hour, are given in the table's last column. They are dependent on isotopic abundance in the target, proton current, the cross sections of the nuclear reactions involved, and the product isotope's half-life. The target element was used in its naturally occurring isotopic composition. Proton current used on each target element depended largely upon type and size of target used. In most cases the results are based on several development runs.

Estimated Product Yields

Radioisotopes listed in Table 1 are only a few of many that can be produced with high yield in the 86-in. cyclotron. Yield estimates for many isotopes that have not yet been produced in this cyclotron are given in Table 2 (right). No distinction was made as to isotope "class." Millicurie-per-hour yields are not given for isotopes having isomeric states with unknown branching ratios because cross sections for formation of the two states are generally unknown and are not amenable to calculation.

Scope of Calculations

Over 250 stable isotopes are available for proton bombardment and many reaction types, *e.g.*, (p,n), $(p,2n)$, $(p,2p)$, (p,d), (p,γ), and (p,α) are possible. Consequently, to reduce the scope of the present calculations, yields were calculated for only the (p,n) and $(p,2n)$ reactions on target isotopes of at least 10% natural abundance that would yield radioactive products with half-lives greater than 100 min.

Proton energy. Maximum energy of the cyclotron is 26 Mev. As a nominal bombarding value, 22 Mev was chosen for yield estimates.

Reactions. Yield estimates were made for the (p,n) and $(p,2n)$ reactions. Although (p,pn) yields are high for medium- and light-weight elements, the reaction does not yield a carrier-free product and, further, the same product can usually be produced by the (p,n) reaction. The (p,α) and $(p,2p)$ reaction cross sections are small except in light- and medium-weight elements, and (p,γ) cross sections are small in all elements. The (p,α) and $(p,2p)$ reactions are excluded because there is considerable doubt as to the

TABLE 2—Estimated Yields for

*Product isotope**	*Half-life†*	*Target isotope*	*Natural abundance (%)*	*Yield/ma-hr* (10^{15} atoms)	*Yield/ma-hr* (mc)
$_4Be^7$	54d	$_3Li^7$	92.5	4.24	170‖
$_{18}A^{37}$	35d	$_{17}Cl^{37}$	24.6	1.8	110
$_{22}Ti^{45}$	3.08h	$_{21}Sc^{45}$	100.0	6.2	10^3
$_{23}V^{48}$	16d	$_{22}Ti^{48}$	73.4	4.3	590
$_{24}Cr^{51}$	27d	$_{23}V^{51}$	99.8	5.6	450
$_{25}Mn^{52m}$	21m				
$_{25}Mn^{52}$	6d	$_{24}Cr^{52}$	83.7	4.4	
$_{26}Fe^{55}$	2.9y	$_{25}Mn^{55}$	100.0	5.1	10
$_{27}Co^{56}$*	18h	$_{26}Fe^{56}$	91.6	3.9	11,000
$_{27}Co^{56}$	80d	$_{26}Fe^{56}$	91.6	4.4	120
$_{30}Zn^{62}$*	9.3h	$_{29}Cu^{63}$	69.0	3.2	18,000
$_{30}Zn^{65}$	250d	$_{29}Cu^{65}$	31.0	1.3	11.0
$_{31}Ga^{66}$	9.4h	$_{30}Zn^{66}$	27.8	1.1	6,300
$_{31}Ga^{67}$*	78h	$_{30}Zn^{68}$	18.6	0.89	590
$_{32}Ge^{68}$*	250d	$_{31}Ga^{69}$	60.1	3.0	26
$_{32}Ge^{69}$	40h	$_{31}Ga^{69}$	60.1	2.4	3,100
$_{32}Ge^{71}$	11.4d	$_{31}Ga^{71}$	39.9	1.6	300
$_{33}As^{71}$*	50h	$_{32}Ge^{72}$	27.4	1.4	1,400
$_{33}As^{72}$	26h	$_{32}Ge^{72}$	27.4	1.0	2,100
$_{33}As^{73}$*	76d	$_{32}Ge^{74}$	36.6	1.8	52
$_{33}As^{74}$	17.5d	$_{32}Ge^{74}$	36.6	1.4	170
$_{34}Se^{75}$	127d	$_{33}As^{75}$	100.0	3.6	62
$_{35}Br^{77}$*	57h	$_{34}Se^{78}$	23.6	1.2	1,100
$_{35}Br^{80m}$	4.6h‡				
$_{35}Br^{80}$	18m	$_{34}Se^{80}$	49.9	1.8	20,000
$_{36}K^{79m}$	55s				
$_{36}K^{79}$	34h‡	$_{35}Br^{79}$	50.6	1.7	2,600
$_{38}Sr^{85m}$	70m				
$_{38}Sr^{85}$	65d	$_{37}Rb^{85}$	72.2	2.3	63.3
$_{38}Sr^{87m}$	2.8h	$_{37}Rb^{87}$	27.8	0.88	16,000
$_{39}Y^{87m}$	14h				
$_{39}Y^{87}$*	80h‡	$_{38}Sr^{88}$	82.7	4.7	3,100
$_{39}Y^{88}$	105d	$_{38}Sr^{88}$	82.7	2.5	52
$_{40}Zr^{89m}$	4.4m				
$_{40}Zr^{89}$	78h	$_{39}Y^{89}$	100.0	2.9	
$_{41}Nb^{90}$	15h	$_{40}Zr^{90}$	51.5	1.5	5,100
$_{41}Nb^{90}$*	15h	$_{40}Zr^{91}$	11.2	0.67	2,300
				2.2¶	7,400¶
$_{41}Nb^{91m}$	62d				
$_{41}Nb^{91}$	~8y‡	$_{40}Zr^{91}$	11.2	0.31	0.24
$_{41}Nb^{91}$*	~8y‡	$_{40}Zr^{92}$	17.1	1.0	0.76
				1.3¶	1.0¶
$_{41}Nb^{92}$	10d	$_{40}Zr^{92}$	17.1	0.49	100
$_{41}Nb^{92m}$*	40d	$_{40}Zr^{94}$	17.4	1.0	56
$_{41}Nb^{94m}$	6.6m				
$_{41}Nb^{94}$	$>10^4$y	$_{40}Zr^{94}$	17.4	0.49	
$_{42}Mo^{93m}$	6.7h				
$_{42}Mo^{93}$	>2y	$_{41}Nb^{93}$	100.0	2.7	
$_{43}Tc^{93m}$	60d				
$_{43}Tc^{95}$	20h	$_{42}Mo^{95}$	15.7	0.42	
$_{43}Tc^{96}$*	20h	$_{42}Mo^{96}$	16.5	0.99	
				1.4¶	
$_{43}Tc^{96m}$	51m				
$_{43}Tc^{96}$	4.3d‡	$_{42}Mo^{96}$	16.5	0.44	220
$_{43}Tc^{97m}$	90d				
$_{43}Tc^{97}$*	$>10^4$y	$_{42}Mo^{95}$	23.8	1.4	
$_{45}Rh^{99}$	4.5h	$_{44}Ru^{99}$	12.8	0.32	3,700
$_{45}Rh^{99}$*	4.5h	$_{44}Ru^{100}$	12.7	0.77	8,900
				1.1¶	13,000¶

Cyclotron-Produced Carrier-Free Radioisotopes

Product isotope*	Half-life†	Target isotope	Natural abundance (%)	Yield/ma-hr (10^{16} atoms)	Yield/ma-hr (mc)
$_{45}Rh^{100}$	19h	$_{44}Ru^{100}$	12.7	0.32	880
$_{45}Rh^{100}$*	19h	$_{44}Ru^{101}$	17.0	1.0	2,800
				1.4¶	3,700¶
$_{45}Rh^{101}$	4.5d	$_{44}Ru^{101}$	17.0	0.43	210
$_{45}Rh^{101}$*	4.5d	$_{44}Ru^{102}$	31.3	1.9	910
				2.3¶	1,100¶
$_{45}Rh^{102}$	210d	$_{44}Ru^{102}$	31.3	0.79	8.2
$_{46}Pd^{103}$	17d	$_{45}Rh^{103}$	100.0	4.0	520
$_{47}Ag^{105}$	40d	$_{46}Pd^{105}$	22.6	0.53	29
$_{47}Ag^{105}$*	40d	$_{46}Pd^{106}$	27.1	1.6	89
				2.1¶	120¶
$_{47}Ag^{106}$	24m				
$_{47}Ag^{106}$	8.3d	$_{46}Pd^{106}$	27.1	0.64	
$_{47}Ag^{110m}$	270d				
$_{47}Ag^{110}$	24s	$_{46}Pd^{110}$	13.5	0.32	
$_{48}Cd^{107}$	6.7h	$_{47}Ag^{107}$	51.4	1.2	9,100
$_{48}Cd^{109}$	470d	$_{47}Ag^{109}$	48.6	1.1	5.2
$_{49}In^{109}$*	4.3h	$_{48}Cd^{110}$	12.4	0.75	900
$_{49}In^{111}$	2.8d	$_{48}Cd^{111}$	12.8	0.28	220
$_{49}In^{111}$*	2.8d	$_{48}Cd^{112}$	24.0	1.4	1,100
				1.7	1,300
$_{49}In^{113m}$	1.74h	$_{48}Cd^{113}$	12.3	0.27	
$_{49}In^{113m}$*	1.74h	$_{48}Cd^{114}$	28.8	1.7	
				2.0¶	
$_{49}In^{114m}$	50d				
$_{49}In^{114}$	72s	$_{48}Cd^{114}$	28.8	0.64	
$_{51}Sb^{117}$*	2.8h	$_{50}Sn^{118}$	24.0	1.4	27,000
$_{51}Sb^{118}$	3.6m				
$_{51}Sb^{118}$	5.1h	$_{50}Sn^{119}$	24.0	0.50	
$_{51}Sb^{119}$*	39h	$_{50}Sn^{120}$	33.0	2.0	2,600
$_{51}Sb^{120}$	16m				
$_{51}Sb^{120}$	6d	$_{50}Sn^{120}$	33.0	0.69	
$_{52}Te^{121m}$	150d				
$_{52}Te^{121}$	17d	$_{51}Sb^{121}$	57.2	1.2	
$_{52}Te^{123m}$	104d	$_{51}Sb^{123}$	42.8	0.87	18
$_{53}I^{124}$*	60d	$_{52}Te^{126}$	18.7	1.1	40
$_{53}I^{126}$	13d	$_{52}Te^{126}$	18.7	0.37	62
$_{53}I^{130}$	12.6h	$_{52}Te^{130}$	34.4	0.68	2,800
$_{54}Xe^{127m}$	75s				
$_{54}Xe^{127}$	33d‡	$_{53}I^{127}$	100.0	1.9	130
$_{56}Ba^{133m}$	39h				
$_{56}Ba^{133}$	10y‡	$_{55}Cs^{133}$	100.0	1.8	1.1
$_{57}La^{137}$	>400y	$_{56}Ba^{137}$	11.3	0.20	
$_{57}La^{137}$*	>400y	$_{56}Ba^{138}$	71.7	4.1	
				4.3¶	
$_{57}La^{138}$	2×10^{11}y	$_{56}Ba^{138}$	71.7	1.3	
$_{58}Ce^{139}$	140d	$_{57}La^{139}$	99.9	1.7	26
$_{59}Pr^{139}$*	4.5h	$_{58}Ce^{140}$	87.5	4.8	56,000
$_{59}Pr^{142}$	19.3h	$_{58}Ce^{142}$	11.1	0.18	500
$_{60}Nd^{140}$*	3.3d	$_{59}Pr^{141}$	100.0	5.5	3,600
$_{60}Nd^{141}$	2.4h	$_{59}Pr^{141}$	100.0	1.6	35,000
$_{61}Pm^{143}$	~300d	$_{60}Nd^{143}$	12.2	0.19	1.4
$_{61}Pm^{143}$*	~300d	$_{60}Nd^{144}$	23.9	1.3	9.3
				1.5¶	11¶
$_{61}Pm^{144}$	~300d	$_{60}Nd^{146}$	23.9	0.37	2.7
$_{61}Pm^{146}$	~2y	$_{60}Nd^{146}$	17.2	0.27	0.80
$_{63}Eu^{147}$	24d	$_{62}Sm^{147}$	15.0	0.22	20
$_{63}Eu^{147}$*	24d	$_{62}Sm^{148}$	11.2	0.59	53
				0.81¶	73¶
$_{63}Eu^{149}$	~120d	$_{62}Sm^{149}$	13.8	0.20	3.5
$_{63}Eu^{152}$	9.3h				
$_{63}Eu^{152}$	13y	$_{62}Sm^{152}$	26.8	0.39	
$_{63}Eu^{154}$	16y	$_{62}Sm^{154}$	22.7	0.33	
$_{64}Gd^{151}$	150d	$_{63}Eu^{151}$	47.8	0.68	9.8
$_{64}Gd^{152}$	236d	$_{63}Eu^{152}$	52.2	0.74	6.8
$_{65}Tb^{154}$*	17.2h	$_{64}Gd^{154}$	14.7	0.75	2,300
$_{65}Tb^{155}$	190d	$_{64}Gd^{155}$	14.7	0.20	2.3
$_{65}Tb^{155}$*	190d	$_{64}Gd^{156}$	20.5	1.0	12
				1.2¶	14¶
$_{65}Tb^{156}$	5.0h	$_{64}Gd^{156}$	20.5	0.28	2,900
$_{65}Tb^{156}$*	5.0h	$_{64}Gd^{157}$	15.7	0.81	8,400
				1.1¶	11,000¶
$_{65}Tb^{157}$	4.7d	$_{64}Gd^{157}$	15.7	0.22	99
$_{65}Tb^{157}$*	4.7d	$_{64}Gd^{158}$	24.9	1.3	590
				1.5¶	690¶
$_{65}Tb^{160}$	73d	$_{64}Gd^{160}$	21.9	0.30	8.9
$_{66}Dy^{159}$	134d	$_{65}Tb^{159}$	100.0	1.3	21
$_{67}Ho^{161}$	4.6h	$_{66}Dy^{161}$	18.9	0.25	2,800
$_{67}Ho^{161}$*	4.6h	$_{66}Dy^{162}$	25.5	1.3	14,000
				1.5¶	17,000¶
$_{67}Ho^{162}$	65d	$_{66}Dy^{162}$	25.5	0.33	11
$_{67}Ho^{162}$*	65d	$_{66}Dy^{163}$	25.0	1.2	42
				1.6¶	53¶
$_{67}Ho^{163}$	5.2d	$_{66}Dy^{163}$	25.0	0.33	140
$_{67}Ho^{163}$*	5.2d	$_{66}Dy^{164}$	28.2	1.4	590
				1.7¶	720¶
$_{68}Er^{165}$	10h	$_{67}Ho^{165}$	100.0	1.3	6,800
$_{69}Tm^{166}$	7.7h	$_{68}Er^{166}$	33.4	0.41	2,700
$_{69}Tm^{166}$*	7.7h	$_{68}Er^{167}$	22.9	1.1	7,500
				1.5¶	10,000¶
$_{69}Tm^{167}$	9.6d	$_{68}Er^{167}$	22.9	0.28	63
$_{69}Tm^{167}$*	9.6d	$_{68}Er^{168}$	27.1	1.3	300
				1.6¶	360¶
$_{69}Tm^{168}$	85d	$_{68}Er^{168}$	27.1	0.33	8.4
$_{69}Tm^{170}$	129d	$_{68}Er^{170}$	14.9	0.18	3.0
$_{70}Yb^{168m}$	50s				
$_{70}Yb^{169}$	32d‡	$_{69}Tm^{169}$	100.0	1.2	79
$_{71}Lu^{170}$*	1.7d	$_{70}Yb^{171}$	14.3	0.67	850
$_{71}Lu^{171}$	8.5d				
$_{71}Lu^{171}$	~1.6y	$_{70}Yb^{171}$	14.3	0.16	
$_{71}Lu^{171}$*	~1.6y	$_{70}Yb^{172}$	21.8	1.0	
				1.2¶	
$_{71}Lu^{172}$	4.0h				
$_{71}Lu^{172}$	6.7d	$_{70}Yb^{172}$	21.8	0.25	
$_{71}Lu^{172}$*	6,7d	$_{70}Yb^{173}$	16.2	0.76	
				1.0¶	
$_{71}Lu^{173}$	~1.4y	$_{70}Yb^{173}$	16.2	0.18	0.78
$_{71}Lu^{173}$*	~1.4y	$_{70}Yb^{174}$	31.8	1.5	6.3
				1.7¶	7.1¶
$_{71}Lu^{174}$	165d	$_{70}Yb^{174}$	31.8	0.36	4.7
$_{71}Lu^{176}$	3.7h	$_{70}Yb^{176}$	12.7	0.14	
$_{72}Hf^{175}$	70d	$_{71}Lu^{175}$	97.4	1.1	33
$_{72}Ta^{176}$*	8.0h	$_{72}Hf^{177}$	18.4	0.83	5,400
$_{73}Ta^{177}$	2.2d	$_{72}Hf^{177}$	18.4	0.19	190
$_{73}Ta^{177}$*	2.2d	$_{72}Hf^{178}$	27.1	1.2	1,200
				1.4¶	1,400¶
$_{73}Ta^{178}$	9.3m				
$_{73}Ta^{178}$	2.1h	$_{72}Hf^{178}$	27.1	0.27	
$_{73}Ta^{178}$*	2.1h	$_{72}Hf^{179}$	13.8	0.62	
				0.89¶	
$_{73}Ta^{179}$	~2y	$_{72}Hf^{179}$	13.8	0.15	0.43
$_{73}Ta^{179}$*	~2y	$_{72}Hf^{180}$	35.3	1.6	4.7
				1.7¶	5.1¶
$_{73}Ta^{180m}$	0.33s				
$_{73}Ta^{180}$	8.1h‡	$_{72}Hf^{180}$	35.3	0.37	2,400
$_{74}W^{181}$	140d	$_{73}Ta^{181}$	100.0	1.0	16
$_{75}Re^{182}$	14h	$_{74}W^{182}$	26.2	0.26	960
$_{75}Re^{182}$*	14h	$_{74}W^{183}$	14.3	0.62	2,300
				0.88¶	3,300¶
$_{75}Re^{183}$	64h				
$_{75}Re^{183}$	120d	$_{74}W^{183}$	14.3	0.14	
$_{75}Re^{183}$*		$_{74}W^{184}$	30.7	1.3	
				1.4¶	
$_{75}Re^{184}$	50d				
$_{75}Re^{184}$	2.2d	$_{74}W^{184}$	30.7	0.30	
$_{75}Re^{186}$	91h	$_{74}W^{186}$	28.7	0.28	160
$_{76}Os^{185}$	95d	$_{75}Re^{185}$	37.1	0.35	8.0
$_{77}Ir^{187}$*	12h	$_{76}Os^{188}$	13.3	0.56	2,400
$_{77}Ir^{188}$	41h	$_{76}Os^{188}$	13.3	0.12	150
$_{77}Ir^{188}$*	41h	$_{76}Os^{189}$	16.1	0.67	860
				0.79¶	1,000¶
$_{77}Ir^{189}$	>100d	$_{76}Os^{189}$	16.1	0.15	
$_{77}Ir^{189}$*	>100d	$_{76}Os^{190}$	26.4	1.1	
				1.3¶	
$_{77}Ir^{190}$	3h				
$_{77}Ir^{190}$	12d	$_{76}Os^{190}$	24.6	0.24	
$_{77}Ir^{192m}$	1.4m				
$_{77}Ir^{192}$	75d	$_{76}Os^{192}$	41.0	0.37	
$_{78}Pt^{191}$	3.0d	$_{77}Ir^{191}$	38.5	0.34	250
$_{78}Pt^{192}$	4.3d	$_{77}Ir^{193}$	61.5	0.54	270
$_{79}Au^{193}$*	15h	$_{78}Pt^{194}$	32.8	1.3	4,600
$_{79}Au^{194}$	39h	$_{78}Pt^{194}$	32.8	0.28	370
$_{79}Au^{194}$*	39h	$_{78}Pt^{195}$	33.7	1.3	1,800
				1.6¶	2,200¶
$_{79}Au^{195}$	180d	$_{78}Pt^{195}$	33.7	0.29	3.5
$_{79}Au^{195}$*	180d	$_{78}Pt^{196}$	25.4	1.0	12
				1.3¶	16¶
$_{79}Au^{196}$	14h				
$_{79}Au^{196}$	5.6d	$_{78}Pt^{196}$	25.4	0.22	
$_{80}Hg^{197m}$	25h				
$_{80}Hg^{197}$	65h	$_{79}Au^{197}$	100.0	0.81	
$_{81}Tl^{196}$	1.8h	$_{80}Hg^{196}$	10.0	0.08	2,300
$_{81}Tl^{196}$*	1.8h	$_{80}Hg^{199}$	16.9	0.65	19,000
				0.72¶	21,000¶
$_{81}Tl^{199}$	7.0h	$_{80}Hg^{199}$	16.9	0.13	990
$_{81}Tl^{199}$*	7.0h	$_{80}Hg^{200}$	23.1	0.88	6,600
				1.0¶	7,600¶
$_{81}Tl^{200}$	27h	$_{80}Hg^{200}$	23.1	0.18	350
$_{81}Tl^{200}$*	27h	$_{80}Hg^{201}$	13.2	0.50	970
				0.68¶	1,300¶
$_{81}Tl^{201}$	72h	$_{80}Hg^{201}$	13.2	0.10	75
$_{81}Tl^{201}$*	72h	$_{80}Hg^{202}$	29.8	1.1	820
				1.2¶	900¶
$_{81}Tl^{202}$	12d	$_{80}Hg^{202}$	29.8	0.23	42
$_{82}Pb^{203}$	52h	$_{81}Tl^{203}$	29.5	0.22	220
$_{83}Bi^{205}$*	14d	$_{82}Pb^{206}$	26.0	0.94	150
$_{83}Bi^{206}$	6.4d	$_{82}Pb^{206}$	26.0	0.19	64
$_{83}Bi^{206}$*	6.4d	$_{82}Pb^{207}$	21.0	0.76	260
				0.95¶	320¶
$_{83}Bi^{207}$	50y	$_{82}Pb^{207}$	21.0	0.15	0.018
$_{83}Bi^{207}$*	50y	$_{82}Pb^{208}$	52.0	1.9	0.22
				2.0¶	0.24¶
$_{84}Po^{208}$*	2.9y	$_{83}Bi^{209}$	100.0	3.5	7.2
$_{84}Po^{209}$	~100y	$_{83}Bi^{209}$	100.0	0.70	0.041

* Isotope is produced by (p,n) reaction unless noted by asterisk, in which case production reaction is $(p,2n)$.

† Half-lives and abundances are taken from the "Chart of the Nuclides," General Electric Co., November, 1952. Radiation energies for each isotope can be found on this chart.

‡ This is the half-life used for calculating curie yields.

¶ This is total yield of isotope from all production reactions listed.

§ This is an experimentally determined yield.

validity of the calculated cross sections, and not enough data is yet available to provide reliable generalizations.

Natural abundance of isotope. If an element of mixed isotopic composition is bombarded to activate one of its low-abundance isotopes, masking activities are induced in the remaining components. Separated stable isotopes may be used to reduce undesired isotope intensity, with the restriction that separation cost adds significantly to total cost and is unfortunately higher for the less abundant isotopes. The rather arbitrary figure of 10% was taken as the lowest practicable concentration for target isotope. The noble gases, Ne, A, Kr, Xe, and Rn, were excluded from consideration because of the difficulty of obtaining appreciable yields from a gaseous internal target.

Product half-life. If an isotope is to be used effectively at a location other than the production site, it is not practical to use an isotope for which transportation time is more than a few half-lives. Even for studies performed locally, the time for removing the target from the machine, separating the active material, and transporting it precludes excessively short half-lives. Table 2 is limited to those isotopes with >100-min half-life.

Calculation Method

Yield estimates are based on the few available, experimentally determined, reaction cross sections and on many additional calculations. A number of approximations were made to simplify the computations, (as explained in the section "Estimating Cyclotron Yields," below) but it is believed that the estimated yields are reasonable.

* * *

The ORNL 86-in. cyclotron is operated by the Electronuclear Research Division. The radioisotope production targets are processed by the Radioisotope Department and the isotopes are distributed through the Radioisotope Sales Department; both are departments of the ORNL Operations Division.

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4. M. O. Stern, *Rev. Mod. Phys.* **21**, 316 (1949)

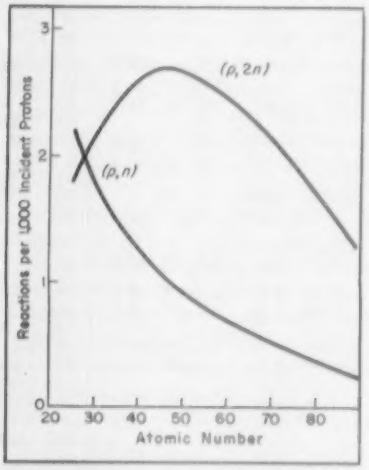

FIG. 3. Estimated thick-target yields for 22-Mev protons

Estimating Cyclotron Yields

Predictions of thick-target yields for a large number of elements when exposed to 22-Mev protons are desired. Because cross-section data in this energy range are meager, it is necessary to resort to theoretical estimates of cross sections. The state of theory of charged-particle nuclear reactions is, however, not completely quantitative in this energy region. The calculation method of the continuum theory described by Blatt and Weisskopf (2) is adopted, despite reservations as to its accuracy. Tabular data on proton ranges for various energies (3) are adapted for convenient numerical integration. The nuclear reaction yield (the number of nuclei of product isotope per incident proton) is given by the relationship

$$y = \int_0^R N\sigma \, dx$$

where $N\sigma$ is total target cross section per unit path, x is distance in proton direction of penetration, and R is effective range. A suitable expression for generation rate in curies was derived by straightforward methods. This summarizes calculation method:

1. *Graphs are prepared showing $\sigma(C)$, the cross section for compound nucleus formation by proton bombardment, as a function of proton energy. For this purpose, tabular data (2) are plotted for atomic numbers 20–90 in steps of ten units. The nuclear radius $r = 1.5 \times 10^{-13}$ cm is used. Extrapolations by the asymptotic formula for large values of proton energy are made as needed.*

2. *The thresholds of the (p,n) reactions are taken as the effective intercepts of the $\sigma(C)$ graphs on the energy axis. The energy difference between thresholds E_1 and E_2 for the (p,n) and $(p,2n)$ reactions is computed as a function of atomic number, Z, for values on the line of greatest isotopic stability Z_A. The Metropolis form of the Weizsacker-Fermi semi-empirical mass formula, quoted by Stern (4), is used for these calculations.*

3. *Cross section $\sigma(p,n)$ is taken as equal to $\sigma(C)$ for the region between the thresholds E_1 and E_2. Values of $\sigma(p,n)$ and $\sigma(p,2n)$ for energies above E_2 are computed from the statistical or temperature model of the nucleus (2) and plotted as a function of energy. No distinction is made between nuclei on the basis of symmetry.*

4. *Differential proton ranges in elements of atomic number 20, 30, . . . were computed by interpolation on a graph of range vs energy for the knowns, Al, A, Cu, Ag, and Pb.*

5. *Numerical integration of the yield relation in the form*

$$g = C\Sigma_i \sigma_i(E)\Delta R_i(E)$$

yielded generation rates for elements as a function of proton energy and atomic number. Here $\sigma(E)$ is reaction cross section at E taken from the graph in **3** *above, $\Delta R(E)$ is a change in range over the energy interval about E, and C is a function of isotopic mass and proton beam current.*

6. *The yields for (p,n) and $(p,2n)$ reactions are adjusted to account for large (p,pn) competition that occurs in the low-mass number range by using experimental data for cross sections of several isotopes. Fig. 3 shows variation of thick-target yields with atomic number. For high Z, the (p,n) yield is small.*

7. *Production rates for specific isotopes are calculated using data obtained in step* **5**. *The usual growth formula of radioactivity calculations is applied to obtain yields. On the assumption that a target would seldom be bombarded for such a length of time that saturation was approached, the linear approximation of the growth relation is used.*

Mapping Radiation Fields With Silver-Activated Phosphate Glass

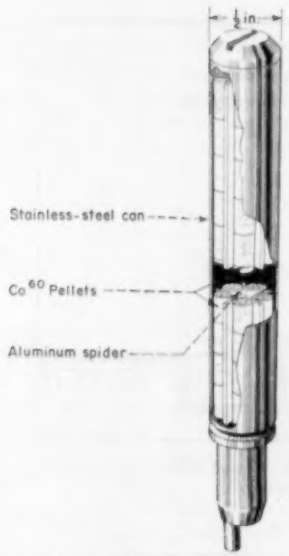

FIG. 1. NRL's Co^{60} source consists of ten stainless-steel cans like the one above. Each contains 50 Co^{60} pellets arranged in five 5-in.-high columns of ten pellets each

Here's a procedure for correcting silver-activated glass dosimeters for fading. Application to mapping dose distribution of 2.5-kilocurie Co^{60} source gives a result that agrees well with computation

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POINT BY POINT knowledge of radiation fields is often desirable. This information is required when it is necessary to specify the extremes in dose delivered. Because of insufficient knowledge of field distributions, full advantage of the output of radioactive sources is often not taken. This is particularly true with respect to the high-rate regions close to the source where the gradient of the field is large.

Absorption changes of silver-activated phosphate glass (*1*) were used to map the gamma-ray field of NRL's 2.5-kilocurie Co^{60} source. This system of dosimetry is simple and reliable. The glass is available in small specimens and can be mounted on any surface with adhesive tape; thus dose can be measured at relatively inaccessible field points. The optical absorption changes in the glass are easily measured with any one of a number of commercially available spectrophotometers.

Because of the increased energy sensitivity of silver-activated glass be-

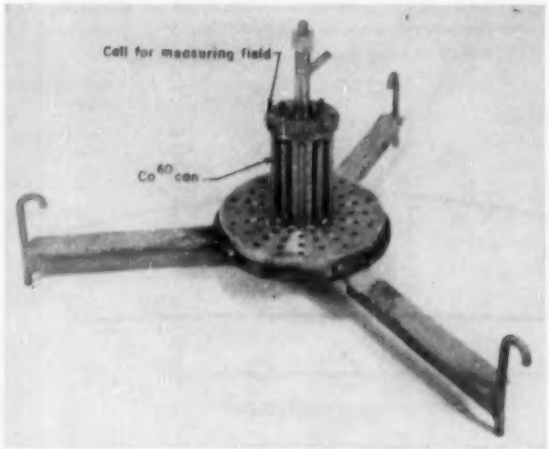

FIG. 2. Source plate on which cans (Fig. 1) are mounted allows many arrangements. Water-tight stainless-steel cell is used to determine radiation pattern within source ring

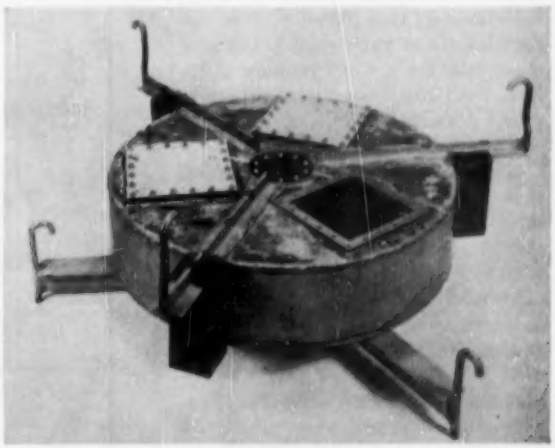

FIG. 3. Cell for irradiations outside ring of sources has 25-in. o.d. During exposures inner cell (Fig. 2) was in position to provide air path through source-ring interior

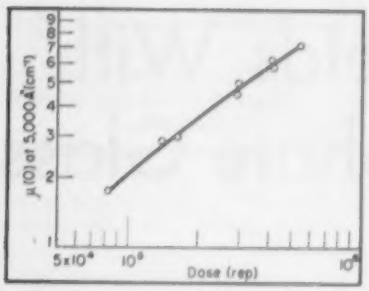

FIG. 4. Calibration curve for silver-activated phosphate glass

low 200 kev (*1*), it is not generally advisable to use this glass in gamma and X-ray fields having spectral components below 200 kev that change with position. Such a situation arises in performing depth-dose measurements (particularly when a low-energy radiation source is employed). No difficulty, however, is involved in mapping fields with a fixed proportion of low-energy radiation. The radiophotoluminescent response of this glass has been used advantageously in depth dose determinations within limits (*2*).

Source and Exposures

The NRL cobalt-60 source (*3*), rated nominally at 2,450 curies in July 1953, is composed of cans like that in Fig. 1 mounted on a source plate at the base of a 12-ft-deep water tank.

Glass exposures were performed with the ten cobalt source cans arranged uniformly on a 3¾-in.-diameter circle as shown in Fig. 2. Dose rates at field positions interior and exterior to this source ring were measured using watertight stainless-steel cells, Figs. 2 and 3. Since cell walls nearest the source cans are extremely thin (0.018 in.) and the path lengths in water prior to entering these cells are a small fraction of an inch, the radiation was predominately primary radiation with a relatively small degraded component.

Glass plates used for field mapping were ⅝ in. square and 0.120–0.130 in. thick. These plates were taped to Plexiglas holders in various positions within the irradiation cells. Exposures ran from 30 min to over 4 hr, depending on intensity at the point of exposure. Optical densities at 5,000 Å were measured with a Beckman DU spectrophotometer ½ hr after exposure. Preirradiation densities were subtracted from these measurements. From the known change in optical density, D, and the thickness of the glass specimen, x, the radiation-induced change in linear absorption coefficient, μ, was computed from $\mu = 2.30D/x$.

Actually μ depends on T, the duration of the exposure, since fading of coloration occurs during irradiation and different length exposures provide different time intervals during which the glass fades. Since all optical-density readings were ½ hr after irradiation, the same fading interval after irradiation is common to all exposures, and hence no specific dependence of μ on the time of measurement is indicated.

The measured values of μ were adjusted for fading in accordance with the procedure described on p. 35.

Dose Pattern

Measured and computed values of dose rate are given in Figs. 5 and 6 for points lying in a diametral plane passing through two radially opposite sources. Measured values represent averages of

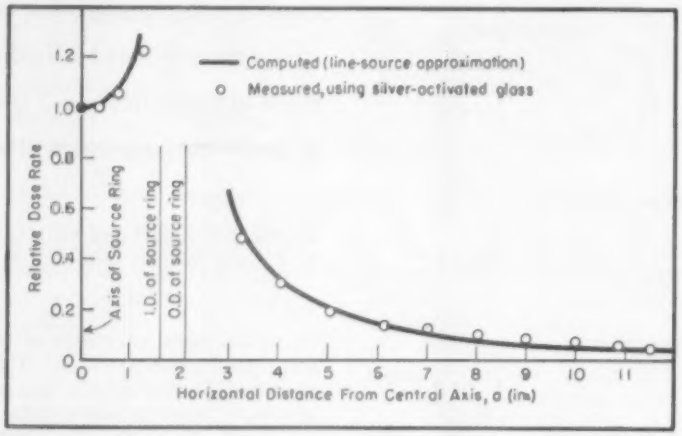
Computed (line-source approximation)
Measured, using silver-activated glass
Relative Dose Rate
Axis of Source Ring
I.D. of source ring
O.D. of source ring
Horizontal Distance From Central Axis, a (in.)

FIG. 5. Relative dose rates along a horizontal line parallel to and 2⅜ in. above a plane passing through bottom of Co^{60}-pellet columns

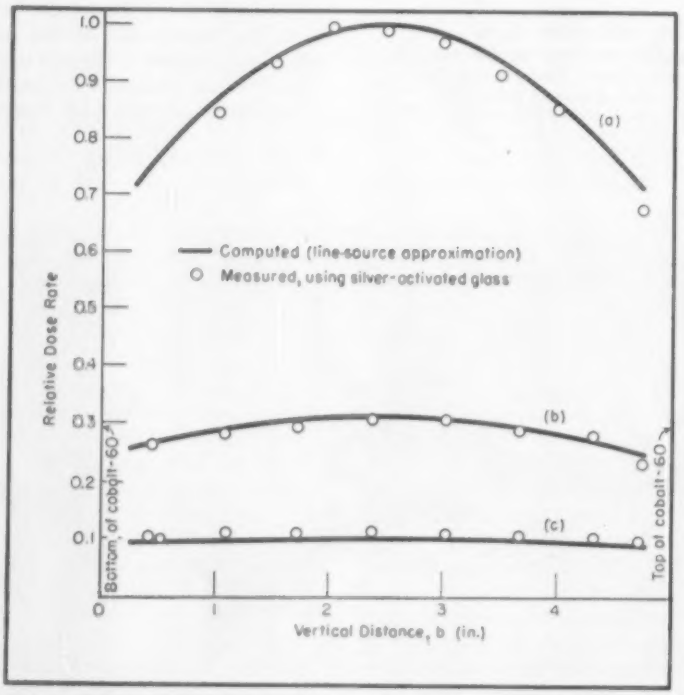

FIG. 6. Relative dose rates along (a) central axis of source ring (b) a parallel line outside source ring, 4$\frac{3}{32}$ in. off axis (c) a similar line 7 in. off axis

several exposures at each point. Computed values correspond to uniform radiating line sources at positions of the cylinder axes, no self-absorption.

To compute the relative dose rate consider the line source of Fig. 7. At a field point (a,b) relative dose rate is

$$R = k \int_0^h \frac{dy}{a^2 + (b-y)^2} = \frac{k}{a}\left[\tan^{-1}\frac{b}{a} + \tan^{-1}\frac{h-b}{a}\right]$$

where k is a constant depending on the choice of reference point.

Since in our case ten 5-in.-high sources are employed, the dose rate relative to common reference point along the central axis is

$$R_{10} = K \sum_{s=1}^{10} \frac{1}{a_s}\left[\tan^{-1}\frac{b}{a_s} + \tan^{-1}\frac{5-b}{a_s}\right]$$

representing addition of contributions from each of the ten sources.

The reference point was chosen on the central axis of the $1\frac{7}{8}$-in.-radius circle of sources, $2\frac{3}{8}$ in. above the plane defined by the bases of the cobalt portions of the sources. Therefore in this case $K = 0.1012$ in.

Unity relative dose rate in Figs. 5 and 6 corresponds to an absolute rate of 5.00×10^5 rep/hr. This is within 12% of the 5.59×10^5 rep/hr obtained with a Victoreen 603 high-rate probe.

* * *

The authors wish to acknowledge the cooperation of W. W. Managan of the Victoreen Instrument Company for providing an early model of their high-rate ion-chamber for use with the NRL source. Thanks are extended to D. L. Dexter for discussion on the correction applied for fading during exposure.

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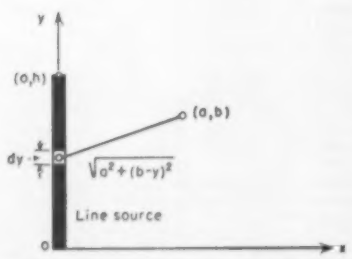

FIG. 7. Geometry for determining dose-rate distribution from a line source

Correcting for Fading During Exposure

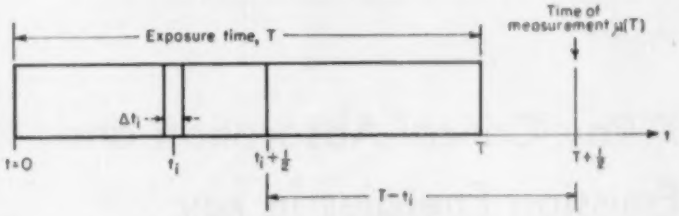

FIG. 8. Diagram illustrating calculation of fading

Calibration data, based on ceric-sulfate dosimetry (4), are given in Fig. 4 for Co^{60}-irradiated glass. The optical density measurements were made ½ hr after the end of short exposures averaging 7 min. Since field-mapping exposures ran to over four hours, it was necessary to apply corrections for fading during exposure so that the calibration curve could be used. That is, we must correct $\mu(T)$, the optical absorption change measured ½ hr after an exposure lasting T hr, back to $\mu(0)$, the absorption-coefficient change that would have been observed had the same dose been administered in zero time.

During the exposure of T hours, consider an arbitrary time increment Δt_i at time t_i (see Fig. 8). If the change in absorption coefficient produced during Δt_i as measured at time $t_i + ½$ is denoted by $\Delta\mu_i(0)$, it follows that $\mu(0)$ is the sum of such $\Delta\mu_i(0)$ taken over all of T.

Let $\Delta\mu_i(T)$ be the contribution to $\mu(T)$ from the dose delivered during Δt_i. The difference between $\Delta\mu_i(T)$ and $\Delta\mu_i(0)$ arises from the fading occurring during $T - t_i$ as indicated in Fig. 8. Defining $f(T - t_i)$ as the fractional decrease in $\Delta\mu_i(0)$ during $T - t_i$, (f is normalized to unity at $T - t_i = 0$)

$$\Delta\mu_i(T) = f(T - t_i)\Delta\mu_i(0) \qquad (1)$$

When exposures fall on the linear portion of the calibration curve (i.e., before saturation occurs) it can be assumed that coloration goes linearly with exposure. Equation 1 therefore becomes

$$\Delta\mu_i(T) = \frac{\mu(0)}{T} f(T - t_i)\Delta t_i \qquad (2)$$

Since exposures in this study were limited to less than 4×10^5 rep, Eq. 2 is a good approximation because coloration is linear with dose over most of this range. In computing corrections for fading during exposures in which saturation doses are applied, it is necessary to take into account the detailed saturation of $\mu(0)$ with dose, a somewhat more complicated problem.

Integrating both sides, Eq. 2 takes the form

$$\mu(T) = \frac{\mu(0)}{T}\int_0^T f(T - t)dt \qquad (3)$$

It has been found that the fading at 5,000 Å for short exposures can be given within a few per cent by

$$f(\tau) = 0.955(\tau + ½)^{-0.067},\ 0 \le \tau \le 100 \text{ hrs}$$

where τ is the time (in hrs) measured from ½ hr after the end of an exposure and $f(\tau)$ is the fractional decline in the change in absorption coefficient normalized to unity at $\tau = 0$. Assuming that fading during an exposure is like that following an exposure, one can write the expression for $f(T - t)$ in Eq. 3 as

$$f(T - t) = 0.955(T - t + ½)^{-0.067}$$

Substituting this expression in Eq. 3 and integrating, one obtains

$$\mu(0) = \frac{T\mu(T)}{1.02(T + ½)^{0.933} - 0.534}$$

Using this equation, we determined $\mu(0)$ from the measured $\mu(T)$. Radiation doses corrected for fading during exposure were then obtained from Fig. 4.

X-Ray Critical-Absorption and Emission Energies in kev

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Increased use of energy-proportional detectors for X-rays has created a need for a table of energy values of K and L absorption and emission series.

The table presented here includes all elements. Most values were obtained by a conversion to kev of tabulated experimental wavelength values (*1–3*); some are from previous energy-value compilations (*4, 5*). Where a choice existed, the value chosen was the one derived from later work. Certain values were determined by interpolation, using Moseley's law. (All this is annotated in footnotes.)

The conversion equations relating energy and wavelength used are (*6*)

$$E\ (\text{kev}) = (12.39644 \pm 0.00017)/\lambda(\text{Å})$$
$$= 12.39644/1.002020\ \lambda(\text{kX unit})$$

In computing values the number of places retained sufficed to maintain the uncertainty in the original source value. The values in the table have been listed uniformly to 1 ev. However, chemical form may shift absorption edges as much as 10–20 ev (*4, 5*).

To discover computational errors a fit was made to Moseley's law. In general the values were consistent, however there were a few irregularities due to the deviation of some input values (*1*). These were retained in the body of the table but a set of values calculated to fit better are footnoted.

* * *

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X-Ray Critical-Absorption and Emission Energies in kev

Atomic Number	*Element*	*K series*					*L series*							
		K_{ab}	$K\beta_2$	$K\beta_1$	$K\alpha_1$	$K\alpha_2$	L_{Iab}	L_{IIab}	L_{IIIab}	$L\gamma_1$	$L\beta_2$	$L\beta_1$	$L\alpha_1$	$L\alpha_2$
1	Hydrogen	0.0136‡												
2	Helium	0.0246‡												
3	Lithium	0.055			0.052									
4	Beryllium	0.116§			0.110									
5	Boron	0.192†			0.185									
6	Carbon	0.283			0.282									
7	Nitrogen	0.399			0.392									
8	Oxygen	0.531			0.523									
9	Fluorine	0.687†			0.677									
10	Neon	0.874*			0.851§		0.048†	0.022†	0.022†					
11	Sodium	1.08*		1.067	1.041		0.055§	0.034§	0.034§					
12	Magnesium	1.303		1.297	1.254		0.063	0.050	0.049					
13	Aluminum	1.559		1.553	1.487	1.486	0.087	0.073**	0.072**					
14	Silicon	1.838		1.832	1.740	1.739	0.118*	0.099**	0.098**					
15	Phosphorus	2.142		2.136	2.015§	2.014§	0.153*	0.129§	0.128§					
16	Sulphur	2.470		2.464	2.308	2.306	0.193*	0.164**	0.163**					
17	Chlorine	2.819¶		2.815	2.622	2.621	0.238*	0.203§	0.202§					
18	Argon	3.203		3.192§	2.957	2.955	0.287*	0.247**	0.245**					
19	Potassium	3.607		3.589	3.313	3.310	0.341*	0.297**	0.294**					
20	Calcium	4.038		4.012	3.691	3.688	0.399*	0.352	0.349			0.344		0.341
21	Scandium	4.496		4.460	4.090	4.085	0.462*	0.411**	0.406**			0.399		0.395
22	Titanium	4.964		−4.931	4.510	4.504	0.530*	0.460**	0.454**			0.458		0.452
23	Vanadium	5.463		−5.427	4.952	4.944	0.604*	0.519**	0.512**			0.519		0.510
24	Chromium	5.988		−5.946	5.414	5.405	0.679*	0.583**	0.574**			0.581		0.571
25	Manganese	6.537		6.490	5.898	5.887	0.762*	0.650**	0.639**			0.647		0.636
26	Iron	7.111		7.057	6.403	6.390	0.849*	0.721**	0.708**			0.717		0.704
27	Cobalt	7.709		7.649	6.930	6.915	0.929*	0.794**	0.779**			0.790		0.775
28	Nickel	8.331	8.328	8.264	7.477	7.460	1.015*	0.871**	0.853**			0.866		0.849
29	Copper	8.980	8.976	8.904	8.047	8.027	1.100*	0.953	0.933			0.948		0.928
30	Zinc	9.660	9.657	9.571	8.638	8.615	1.200*	1.045	1.022			1.032		1.009

Atomic Number	Element	K series					L series							
		K_{ab}	$K\beta_2$	$K\beta_1$	$K\alpha_1$	$K\alpha_2$	L_{Iab}	L_{IIab}	L_{IIIab}	$L_{\gamma 1}$	$L\beta_2$	$L\beta_1$	$L\alpha_1$	$L\alpha_2$
31	Gallium	10.368	10.365	10.263	9.251	9.234	1.30*	1.134**	1.117**			1.122	1.096	
32	Germanium	11.103	11.100	10.981	9.885	9.854	1.42*	1.248**	1.217**			1.216	1.186	
33	Arsenic	11.863	11.863	11.725	10.543	10.507	1.529	1.359	1.323			1.317	1.282	
34	Selenium	12.652	12.651	12.495	11.221	11.181	1.652	1.473	1.434			1.419	1.379	
35	Bromine	13.475	13.465	13.290	11.923	11.877	1.794§	1.599**	1.552**			1.526	1.480	
36	Krypton	14.323	14.313	14.112	12.648	12.597	1.931§	1.727**	1.675**			1.638§	1.587**	
37	Rubidium	15.201	15.184	14.960	13.394	13.335	2.067	1.866	1.806			1.752	1.694	1.692
38	Strontium	16.106	16.083	15.834	14.164	14.097	2.221	2.008	1.941			1.872	1.806	1.805
39	Yttrium	17.037	17.011	16.736	14.957	14.882	2.369	2.154	2.079			1.996	1.922	1.920
40	Zirconium	17.998	17.969	17.666	15.774	15.690	2.547	2.305	2.220	2.302	2.219	2.124	2.042	2.040
41	Niobium	18.987	18.951	18.621	16.614	16.520	2.706	2.467**	2.374	2.462	2.367	2.257	2.166	2.163
42	Molybdenum	20.002	19.964	19.607	17.478	17.373	2.884	2.627	2.523	2.623	2.518	2.395	2.293	2.290
43	Technetium	21.054§	21.012§	−20.585¶	18.410¶	18.328¶	3.054§	2.795§	2.677§	2.792§	2.674§	2.538§	2.424§	2.420§
44	Ruthenium	22.118	22.072	21.655	19.278	19.149	3.236§	2.966	2.837	2.964	2.836	2.683	2.558	2.554
45	Rhodium	23.224	23.169	22.721	20.214	20.072	3.419	3.145	3.002	3.144	3.001	2.834	2.696	2.692
46	Palladium	24.347	24.297	23.816	21.175	21.018	3.617	3.329	3.172	3.328	3.172	2.990	2.838	2.833
47	Silver	25.517	25.454	24.942	22.162	21.988	3.810	3.528	3.352	3.519	3.348	3.151	2.984	2.978
48	Cadmium	26.712	26.641	26.093	23.172	22.982	4.019	3.727	3.538	3.716	3.528	3.316	3.133	3.127
49	Indium	27.928	27.859	27.274	24.207	24.000	4.237	3.939	3.729	3.920	3.713	3.487	3.287	3.279
50	Tin	29.190	29.106	28.483	25.270	25.042	4.464	4.157	3.928	4.131	3.904	3.662	3.444	3.435
51	Antimony	30.486	30.387	29.723	26.357	26.109	4.697	4.381	4.132	4.347	4.100	3.843	3.605	3.595
52	Tellurium	31.809	31.698	30.993	27.471	27.200	4.938	4.613	4.341	4.570	4.301	4.029	3.769	3.758
53	Iodine	33.164	33.016	32.292	28.610	28.315	5.190	4.856	4.559	4.800	4.507	4.220	3.937	3.926
54	Xenon	34.579	34.446¶	33.644	29.802¶	29.485¶	5.452	5.104	4.782	5.036§	4.720§	4.422§	4.111§	4.098§
55	Cesium	35.959	35.819	34.984	30.970	30.623	5.720	5.358	5.011	5.280	4.936	4.620	4.286	4.272
56	Barium	37.410	37.255	36.376	32.191	31.815	5.995	5.623	5.247	5.531	5.156	4.828	4.467	4.451
57	Lanthanum	38.931	38.728	37.799	33.440	33.033	6.283	5.894	5.489	5.789	5.384	5.043	4.651	4.635
58	Cerium	40.449	40.231	39.255	34.717	34.276	6.561	6.165†	5.729	6.052	5.613	5.262	4.840	4.823
59	Praseodymium	41.998	41.772	40.746	36.023	35.548	6.846	6.443	5.968	6.322	5.850	5.489	5.034	5.014
60	Neodymium	43.571	43.298¶	42.269	37.359	36.845	7.144	6.727	6.215	6.602	6.090	5.722	5.230	5.208
61	Promethium	45.207§	44.955§	−43.945¶	38.649¶	38.160¶	7.448§	7.018§	6.466§	6.891§	6.336§	5.956	5.431	5.408§
62	Samarium	46.846	46.553¶	45.400	40.124	39.523	7.754	7.281¶	6.721	7.180	6.587	6.206	5.636	5.609
63	Europium	48.515	48.241	47.027	41.529	40.877	8.069	7.624	6.983	7.478	6.842	6.456	5.846	5.816
64	Gadolinium	50.229	49.961	48.718	42.983	42.280	8.393	7.940	7.252	7.788	7.102	6.714	6.059	6.027
65	Terbium	51.998	51.737	50.391	44.470	43.737	8.724	8.258	7.519	8.104	7.368	6.979	6.275	6.241
66	Dysprosium	53.789	53.491	52.178	45.985	45.193	9.083	8.621¶	7.850¶	8.418	7.638	7.249	6.495	6.457
67	Holmium	55.615	55.292**	53.934§	47.528	46.686	9.411	8.920	8.074	8.748	7.912	7.528	6.720	6.680
68	Erbium	57.483	57.088	55.690	49.099	48.205	9.776	9.263	8.364	9.089	8.188	7.810	6.948	6.904
69	Thulium	59.335¶	58.969**	57.576¶	50.730	49.762	10.144	9.628	8.652	9.424	8.472	8.103	7.181	7.135
70	Ytterbium	61.303	60.959	59.352	52.360	51.326	10.486	9.977	8.943	9.779	8.758	8.401	7.414	7.367
71	Lutecium	63.304	62.946	61.282	54.063	52.959	10.867	10.345	9.241	10.142	9.048	8.708	7.654	7.604
72	Hafnium	65.313	64.936	63.209	55.757	54.579	11.264	10.734	9.556	10.514	9.346	9.021	7.898	7.843
73	Tantalum	67.400	66.999	65.210	57.524	56.270	11.676	11.130	9.876	10.892	9.649	9.341	8.145	8.087
74	Tungsten	69.508	69.090	67.233	59.310	57.973	12.090	11.535	10.198	11.283	9.959	9.670	8.396	8.333
75	Rhenium	71.662	71.220	69.298	61.131	59.707	12.522	11.955	10.531	11.684	10.273	10.008	8.651	8.584
76	Osmium	73.860	73.393	71.404	62.991	61.477	12.965	12.383	10.869	12.094	10.596	10.354	8.910	8.840
77	Iridium	76.097	75.605	73.549	64.886	63.278	13.413	12.819	11.211	12.509	10.918	10.706	9.173	9.098
78	Platinum	78.379	77.866	75.736	66.820	65.111	13.873	13.268	11.559	12.939	11.249	11.069	9.441	9.360
79	Gold	80.713	80.165	77.968	68.794	66.980	14.353	13.733	11.919	13.379	11.582	11.439	9.711	9.625
80	Mercury	83.106	82.526	80.258	70.821	68.894	14.841	14.212	12.285	13.828	11.923	11.823	9.987	9.896
81	Thallium	85.517	84.904	82.558	72.860	70.820	15.346	14.697	12.657	14.288	12.268	12.210	10.266	10.170
82	Lead	88.001	87.343	84.922	74.957	72.794	15.870	15.207	13.044	14.762	12.620	12.611	10.549	10.448
83	Bismuth	90.521	89.833	87.335	77.097	74.805	16.393	15.716	13.424	15.244	12.977	13.021	10.836	10.729
84	Polonium	93.112	92.386	89.809	79.296	76.868	16.935	16.244	13.817	15.740	13.338	13.441	11.128	11.014
85	Astatine	95.740	94.976	92.319	81.525	78.956	17.490	16.784	14.215	16.248	13.705	13.873	11.424	11.304
86	Radon	98.418	97.616	94.877	83.800	81.080	18.058	17.337	14.618	16.768	14.077	14.316	11.724	11.597
87	Francium	101.147	100.305	97.483	86.119	83.243	18.638	17.904	15.028	17.301	14.459	14.770	12.029	11.894
88	Radium	103.927	103.048	100.136	88.485	85.446	19.233	18.481	15.442	17.845	14.839	15.233	12.338	12.194
89	Actinium	106.759	105.838	102.846	90.894	87.681	19.842	19.078	15.865	18.405	15.227	15.712	12.650	12.499
90	Thorium	109.630	108.671	105.592	93.334	89.942	20.460	19.688	16.296	18.977	15.620	16.200	12.966	12.808
91	Protactinium	112.581	111.575	108.408	95.851	92.271	21.102	20.311	16.731	19.559	16.022	16.700	13.291	13.120
92	Uranium	115.591	114.549	111.289	98.428	94.648	21.753	20.943	17.163	20.163	16.425	17.218	13.613	13.438
93	Neptunium	118.619	117.533	114.181	101.005	97.023	22.417	21.596	17.614	20.774	16.837	17.740	13.945	13.758
94	Plutonium	121.720	120.592	117.146	103.653	99.457	23.097	22.262	18.066	21.401	17 254	18.278	14.279	14.082
95	Americium	124.876	123.706	120.163	106.351	101.932	23.793	22.944	18.525	22.042	17.677	18.829	14.618	14.411
96	Curium	128.088	126.875	123.235	109.098	104.448	24.503	23.640	18.990	22.699	18.106	19.393	14.961	14.743
97	Berkelium	131.357	130.101	126.362	111.896	107.023	25.230	24.352	19.461	23.370	18.540	19.971	15.309	15.079
98	Californium	134.683	133.383	129.544	114.745	109.603	25.971	25.080	19.938	24.056	18.980	20.562	15.661	15.420
99		138.067	136.724	132.781	117.646	112.244	26.729	25.824	20.422	24.758	19.426	21.166	16.018	15.764
100		141.510	140.122	136.075	120.598	114.926	27.503	26.584	20.912	25.475	19.879	21.785	16.379	16.113

For $Z \leq 69$, values without symbols are derived from (*1*). Values prefixed with a − sign are $K\beta_{1+3}$.

For $Z \geq 70$, absorption-edge values are from (*4*) in the case of Z = 70–83, 88, 90, and 92; remaining absorption edges to Z = 100 are obtained from these by least-squares quadratic fitting. All emission values for $Z \geq 70$ are derived from the preceding absorption edges, and others based on (*4*), using the transition relations $K\alpha_1 = K_{ab} - L_{III}$, $K\alpha_2 = K_{ab} - L_{II}$, $K\beta_1 = K_{ab} - M_{III}$, etc.

* Obtained from R. D. Hill, E. L. Church, J. W. Mihelich (*5*). † Derived from Compton and Allison (*2*). ‡ Derived from C. E. Moore (*3*).

¶ Values derived from Cauchois and Hulubei (*1*) which deviate from the Moseley law. Better-fitting values are: Z = 17, K_{ab} = 2.826; Z = 43, $K\alpha_1$ = 18.370, $K\alpha_2$ = 18.250, $K\beta_1$ = 20.612; Z = 54, $K\alpha_1$ = 29.779, $K\alpha_2$ = 29.463, $K\beta_2$ = 34.398; Z = 60, $K\beta_2$ = 43.349; Z = 61, $K\alpha_1$ = 38.726, $K\alpha_2$ = 38.180, $K\beta_1$ = 43.811; Z = 62, $K\beta_2$ = 46.581, L_{II} = 7.312; Z = 66, L_{II} = 8.591, L_{III} = 7.790; Z = 69, K_{ab} = 59.382, $K\beta_1$ = 57.487.

§ Calculated by method of least squares. ** Calculated by transition relations.

Nitrogen Fixation in a Nuclear Reactor

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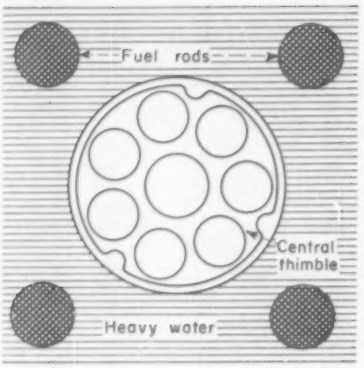

FIG. 1. Plan view cross section of CP-3 in central-thimble region. Jacketed natural-uranium rods are on $5\frac{3}{8}$-in. centers

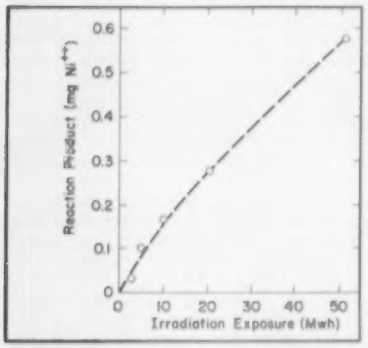

FIG. 2. Formation of soluble nickel in CP-3's central thimble in vitreous-silica ampule containing 17.7 cm³ air saturated at 28° C at total pressure of 1 atmos., and 5.1 cm of 28-mil nickel wire

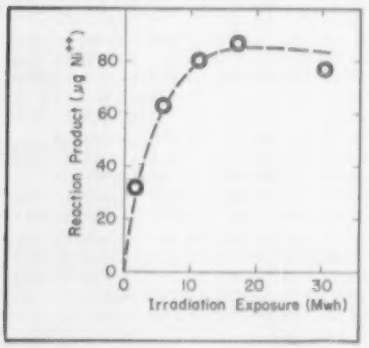

FIG. 3. Formation of soluble nickel in CP-3's central thimble in vitreous-silica ampule containing 17.7 cm³ air of humidity 4.03 mm Hg of water at a total pressure of 1 atmos. at 28° C, and 5.1 cm of 28-mil nickel wire

How nitrogen and oxygen react to coat nitric-acid-susceptible metals in the presence of water vapor in Argonne's CP-3 heavy-water reactor was studied by determining the reaction product formed on nickel. The optical properties of the reaction's initial product conformed to $Ni(NO_3)_2 \cdot 6H_2O$, and the formation of soluble nickel compounds proceeded until about 1/2.7 moles of nickel had been rendered soluble for each mole of water originally present. This suggests that the reaction proceeds beyond the consumption of water by the formation of $Ni(NO_3)_2 \cdot 3H_2O$.

Earlier studies of nitrogen fixation in a reactor showed that the nitrogen and oxygen combined in the gas phase (*1*). Such a reaction is not unexpected since oxygen and nitrogen are known to combine under a variety of ionizing conditions. In some further studies, an attempt to correlate the effect with the slow-neutron flux failed (*2*).

We observed that corrosion films developed on metal exposed to air in the CP-3 reactor. This effect was attributed to chemical reaction between exposed metals and products formed in the air.

Some of the practical consequences of exposing metals to humid air in a reactor have been discussed previously (*3,4*) (see box, p. 39). Oxides were found to form in copious amounts when lead was exposed to radiation in humid oxygen. Formation of nitrates was noted on aluminum, cobalt, copper, lead, nickel and Inconel when they were exposed in humid air in a nuclear reactor. These metals are all subject to nitric-acid corrosion. But gold and stainless steel, which are not corroded by nitric acid, remained uncoated. No corrosion was seen when the atmospheric oxygen, nitrogen, or air was dry. To produce appreciable quantities of reaction products on the metal investigated, water vapor had to be present.

Thus it was concluded that the essential phenomenon did not involve the metal, but rather the fixation of nitrogen.

Experimental Method

Nickel samples were used because they did not become intensely radioactive, did not show complicating effects (like those shown by lead), were not rapidly soluble in water, and the products could be analyzed easily.

Each cleaned and polished 0.028-in.-diameter by 5.1-cm-long nickel-wire sample was prepared for irradiation by being inserted in 17.7-cm³* ampules made of 18-mm-o.d. vitreous-silica tubing. The desired atmosphere† was swept through the ampule for several hours using a capillary tube in its neck. Then the tube was withdrawn and

* Where noted, ampules of different size were used.

the 17.7-cm³ ampule was sealed tight.

The sealed ampules were placed in thin-wall aluminum tubes and irradiated by placing them near the bottom of one of the small tubes in the central thimble of the Argonne CP-3 reactor (*5*). A cross section of CP-3 in this region is shown in Fig. 1. Irradiation temperatures were about 40° C. After removal from the reactor, the ampules were permitted to stand until the radioactivity had decayed sufficiently. Within several weeks, they were opened.

If a chemical analysis was desired, the contents were washed out with water, the washings diluted to known volume, and an aliquot analyzed. If examination of the solid product was desired, a sample was taken from the surface of the wire.

Experimental Results

No reaction products were found on nickel wires irradiated for 30 Mwh in 8.5-cm³ ampules containing dry oxygen, dry nitrogen, or dry air. After 30 Mwh irradiation in moist oxygen, a small amount of a black product, possibly an oxide, was found on the wire but not positively identified.

A sample was prepared in an ampule attached to a manifold to which was attached a flask of water. The manifold was evacuated, then sealed off from the pumps to permit it and the ampule to be filled with water vapor (20–30 mm Hg), then the ampule was sealed. No reaction products were found on the wire in this ampule after 30 Mwh irradiation. But copious quantities of a light-green water-soluble salt were found on a nickel wire after 30 Mwh irradiation in humid air that had been saturated at 28° C. The optical properties (interference figure, refraction indices) were found to correspond to those of a sample of commercial $Ni(NO_3)_2 \cdot 6H_2O$: biaxial negative, $\alpha = 1.47$, $\beta = 1.55$, $\gamma = 1.56$. The washings of this sample were analyzed for Ni^{++}, NO_2^-, and NO_3^- by using colorimetric methods, the Ni^{++} by dimethylglyoxime (*6*), the nitrite by α-naphylamine (*6*), and the nitrate by brucine (*7*). There were 155 μg Ni^{++}, 75 μg NO_3^-, and no (<5 μg) NO_2^-. Thus Ni^{++} and NO_3^- were present in the molar ratio 1/2.

An attempt had been made to identify the product obtained on a cobalt wire by the powder X-ray diffraction method, but no success was attained because the diffraction patterns were too diffuse. No attempts were made to identify the product on the nickel wire by this means.

A number of irradiations were conducted for various lengths of time using 17.7 cm³ ampules. Figure 2 shows results of irradiations in which the atmosphere was air that had been saturated with water at 28° C. Figure 3 shows the results of irradiations in which the atmosphere was air containing water vapor at a pressure of 4.03 mm Hg.

Significance

Since no soluble nickel was formed when nickel was irradiated in dry air, it was reasonable to expect that soluble-nickel formation would saturate at smaller exposures as humidity was lowered. Comparison of Figs. 2 and 3 shows this to be the case.

The decline indicated by the long exposures in Fig. 3 may not be significant as this much scatter among unmonitored reactor irradiations is quite common. Thus it may be concluded that saturation in this case occurs at about 85 μg of nickel rendered soluble.

† The oxygen and air were from commercial cylinders. The nitrogen was freed of oxygen by passing it through two 2-ft columns filled with porous copper (prepared by reducing wire-form copper oxide) heated to 350° C. Saturated humid gas was prepared by passing the gas successively through two 1½-in. columns 20-in. long that had been placed in a thermostat and filled with glass beads covered with water. The temperature was read on a thermometer immersed in the column at the exit. Unsaturated humid gas was prepared by mixing saturated humid gas and dried gas (passed through columns of Drierite) in the desired ratio as determined by flowmeters. The vapor pressure of unsaturated humid gas was checked by weighing a drying tube filled with anhydrone through which the gas flowed for a measured time at a rate measured by a flowmeter. A further check was made by determining the dew point of the gas.

What Nitrogen Fixation Does

Atmospheric nitrogen is fixed under conditions of ionization. Under these conditions, decomposition usually ensues and causes a low equilibrium concentration of oxides of nitrogen. But if water vapor and a nitric-acid-reacting metal are present, the fixed nitrogen is effectively removed as nitrate and fixation continues. Because the reaction products are often hygroscopic, under certain conditions they will start or accelerate electrolytic corrosion.

Examples of these phenomena include (*4*):

- Radioactive particles were transferred to samples in an aluminum can irradiated in a reactor. The deposits probably were products of aluminum-nitrate hydrolysis.
- Strongly radioactive solid samples leave surprising amounts of contamination on surfaces they contact. It is suspected that surface deposits contribute to this.
- Cobalt wires irradiated in air in a reactor had dark deposits over most of the wire and some violet-red deposits. Similar wires irradiated in Lusteroid tubes (a cellulose nitrate plastic) had heavier violet deposits.
- A nickel mirror became transparent when irradiated in air in a reactor. Under a microscope, the part that had been nickeled appeared as a very light green transparent incoherent coating, probably hydrated nickel nitrate.
- Nickel suspension wires in a reactor parted during humid summer days.
- A heavy blue-green deposit, probably a hydrated cupric nitrate, was found on a copper battery clip used to suspend a polonium sample in a jar filled with humid air.
- A deposit, mostly lead oxide, was found on a steel spring from an evacuated aluminum irradiation can that had contained some lead in a distant part. Presumably, convection currents formed by temperature gradients in some residual gas and water vapor carried corrosion-product particles through the can and, because of electrical circumstances, the deposit built up on the spring.

Because radioactive corrosion products can be spread by wiping, capillarity, or gas convection currents, the resultant contamination might be a nuisance, a health hazard, or a source of spurious scientific results.

Energy Dissipated in the Gas

Computation of the energy dissipated in the gas is very difficult for nuclear reactor experiments because of the large number of individual sources immersed in strongly absorbing media.

Several attempts have been made to determine dosages experimentally (*10, 11, 12*). However, because everything put in a thermal-neutron reactor becomes both a source and an absorber, there can be extreme variation* from one experiment to another. Thus, their results can be considered only to be illustrative of particular experimental arrangements whose details are not described.

An elementary theoretical treatment has been given in which the gamma-ray absorption law $\exp[u(x) - (\mu/\rho)x]$, where u is the buildup coefficient due to the degradation of gamma-ray energies and μ/ρ, the mass absorption coefficient, was approximated by $e^{-\beta x}$, where β is a guessed-at mean absorption coefficient (*13*). This simplification yielded surprisingly good estimates when compared with experimental information available at the time. It is applied here.

The energy sources that must be considered are: gamma rays from the fissioning fuel rods, from the moderator, from the aluminum thimble and can, from the silica ampule and the nickel rod; fast neutron recoils involving scattering of oxygen, nitrogen, and hydrogen in the gas; and C^{14} recoils and protons from the $N(n,p)C^{14}$ reaction in the gas.

Other ionization sources are probably sufficiently small in comparison that they can be neglected. The doses from the sources are computed in terms of a multiple of 83 ergs/gm that their radiation would dissipate in 1 gm of material placed at the point of interest.

Dose from gammas. For gamma rays in the Compton range, the dose in all but the heaviest elements or hydrogenous substances can be written: Dosage (rep/sec) = $\phi(\text{Mev/cm}^3\text{/sec})1.6 \times 10^{-6}(\text{erg/Mev})\beta(\text{cm}^{-1})\rho^{-1}(\text{cm}^3\text{/gm})$ 83^{-1} (rep/gm/erg) = $1.93 \times 10^{-6}(\beta/\rho)\phi$, where the numbers are explained by the accompanying units, a ρ corresponding to the β is used, and the flux, ϕ, is used in the sense discussed elsewhere (*14*); it is computed from the generation (proportional to the local neutron flux) by means of integrals of the form

$$\int s e^{-\beta r} d\omega$$

(where s is the generation and ω the solid angle) taken over the body. For the fuel rods an approximation was used. The emergent flux was calculated by an integral of this sort, and the flux at the sample was calculated by assuming the rod to be a line source whose strength was that of the emergent flux.

The results obtained for the various sources were: rods, 350; moderator, 7.1; thimble and irradiation can, 48; silica tube, 2; nickel wire, 4; or a total of 411 rep/sec.

Dose from fast neutrons. To compute the contributions from fast neutrons, it is assumed that the fast-neutron flux as a function of energy, $\phi(E)$, in the central thimble of CP-3 can be represented as $4 \times 10^{10}/E$ up to 1 Mev.† Thus the energy conveyed to the gas is

$$\sum_i \int_0^1 \zeta_i E \sigma_i A_i (4 \times 10^{10}/E)\, dE = \sum_i 4 \times 10^{10} \zeta_i A_i \int_0^1 \sigma_i\, dE$$

where A is the number of atoms, ζ is the average fraction of the energy conveyed to the atom in a neutron collision, and σ is the atomic scattering cross section. The values of ζ for hydrogen, nitrogen, and oxygen are 0.5, 0.12, and 0.11, respectively. For the 17.7 cm^3 of gas used here containing 28 mm of water and 722 mm of air at a temperature of 28° C, the respective values of A for the hydrogen, nitrogen, and oxygen were 0.32, 6.4, and 1.8×10^{20} atoms, possessing a total weight of 0.02 gm. At these energies the total cross sections (*15*) can be used for the scattering cross sections. The integrals were obtained graphically and were 7.6, 2.4, and 4.2×10^{24} cm^2 Mev/atom, respectively. This gives 1.6×10^7 Mev/sec for the energy conveyed to the gas.‡ Thus, the gamma-ray dosage equivalent to the neutron scattering energy is $1.6 \times 10^7(\text{Mev/sec})0.02^{-1}(\text{gm}^{-1})1.6 \times 10^{-6}(\text{erg/Mev})\,83^{-1}$ (rep/gm/erg) = 15 rep/sec. A fraction of this was transmitted to the walls, but the correction is neglected.

Dose from $N(n,p)C^{14}$ reaction. The dose due to the $N(n,p)C^{14}$ reaction is large. Of the 0.63 Mev/capture, about 0.043 Mev is dissipated by the C^{14} recoil, all of whose energy can be assumed dissipated in the gas. The remaining 0.59 Mev resides in the proton, which has a range of about 1 cm. This range is comparable to the vessel dimensions. The vessel was cylindrical, about 9 cm long; hence, from its volume of 17.7 cm^3, the radius must have been about 0.75 cm. With a particle of so short a range the length of the cylinder can be considered infinite for this calculation. The energy dissipated in the gas can be obtained by integrating the product of the range-energy function and the distribution-of-path-lengths-in-a-cylinder function. The first function is well known (*16, 17*). The density of all possible interior path lengths to the surface of an infinite cylinder, $N(p)$, is (*18*): for $p < 2$, $N(p) = (2/3\pi)[2\mathbf{E}(p/2) - \mathbf{B}(p/2)]$; for $p > 2$, $N(p) = (2/3\pi p)[2\mathbf{B}(2/p) - \mathbf{E}(2/p)]$; where p is the length of path expressed in units of the radius of the cylinder, and $\mathbf{E}$ and $\mathbf{B}$ are the notations used for the elliptic integrals (*18*). The form of $N(p)$ is shown in Fig. 4 (*13*). The fraction of the energy expended in the gas is

$$(1/0.59) \int_0^2 N(p)E(p)\, dp + \int_\lambda^\infty N(p)\, dp$$

where E is the energy lost by the proton in a distance p. The data for the integration are given in the table. The integrals were obtained graphically and were found to be 0.32 + 0.33 = 65%. Thus, the total energy contributed by the $N(n,p)C^{14}$ reaction per gram of sample is $(0.63\ \text{Mev})(6.4 \times 10^{20}\ \text{atoms})(10^{12}\ \text{n/cm}^2\text{/sec})(1.7 \times 10^{-24}\ \text{cm}^2\text{/atom/n})\,(0.02^{-1}\ \text{gm}^{-1}) = 3.4 \times 10^{10}$ Mev/gm/sec. The fraction conveyed to the gas is 0.07 by C^{14} and 0.67, 0.65×0.93, by the proton. Thus, the gamma-ray dose equivalent to the $N(n,p)C^{14}$ reaction is $0.67(3.4 \times 10^{10}\ \text{Mev/gm/sec})(1.6 \times 10^{-6}\ \text{erg/Mev})[(1/83)(\text{rep/gm/erg})] = 440$ rep/sec.

* It is quite simple to arrange conditions in which the ionization changes by orders of magnitude per foot in a nuclear reactor.

† This value was arrived at by comparing the radiation damage rates in the central thimble with nuclear reactor positions for which the slowing down had been studied.

‡ This result is consistent with our interpretation of calorimetric results obtained by observing heat produced in various samples put into a nuclear reactor (*11*).

The amount of water in the ampule was about $(4.03/750)(273/301)(17.7/22{,}400) = 3.85 \times 10^{-6}$ moles, and the maximum amount of nickel rendered soluble was about $85 \times 10^{-6}/59 = 1.44 \times 10^{-6}$ moles, or about 2.7 moles of water for each mole of Ni^{++}. This suggests that the over-all reaction near saturation is

$$Ni + 3H_2O + N_2 + 3O_2 \rightarrow Ni(NO_3)_2 \cdot 3H_2O$$

It is presumed that at some point in the dehydration curve of $Ni(NO_3)_2 \cdot 3H_2O$, the removal rate of fixed nitrogen declines under the conditions of these irradiations. The concentration of nitrogen oxides in the gas phase would then increase. It has been concluded that these initial products of nitrogen fixation decompose under irradiation (*8*). Thus it is assumed that, with a declining removal rate of nitrogen oxides from the gas phase, the concentration of these oxides increases until their decomposition rate becomes equal to their formation rate, and saturation ensues.

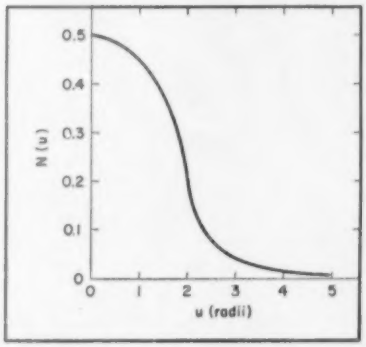

FIG. 4. *N(u)*, the distribution of path lengths within the infinite cylinder

Data for Integrating N(u) E(u) for R = 0.75 cm, ρ = 1.114 mg/cm³

u (mg/cm²)	$E(u)$ (Mev)	u (radii)	$N(u)$	$N(u)\,E(u)$ (Mev)
0	0	0	0.500	0
0.1	0.08	0.12	0.498	0.040
0.2	0.15	0.24	0.496	0.074
0.3	0.21	0.36	0.492	0.103
0.4	0.27	0.48	0.488	0.132
0.5	0.32	0.60	0.482	0.154
0.6	0.36	0.72	0.474	0.171
0.7	0.40	0.84	0.464	0.186
0.8	0.44	0.96	0.453	0.199
0.9	0.48	1.08	0.439	0.211
1.0	0.51	1.20	0.425	0.217
1.1	0.54	1.32	0.407	0.219
1.23	0.59	1.47	0.379	0.224

Nitrogen fixation rate. The initial rate of nitrogen fixation can be computed from Fig. 2. The nickel was rendered soluble at the initial rate of 20 μg Ni/Mwh, or $(20/17.7)\ 7.64 \times 10^{-5} = 8.63 \times 10^{-5}$ μg Ni/cm³/sec at a reactor power of 275 kw. Since two atoms of nitrogen have been fixed for each atom of nickel rendered soluble, the rate of nitrogen fixation was $8.63 \times 10^{-5}(10^{-6})(2/59)6.02 \times 10^{23} = 1.8 \times 10^{12}$ atoms N/cm³/sec.

Yield. To calculate the approximate yield, it is necessary to compute the energy dissipated in the gas. From such a computation (see box, page 40), it is concluded that the gamma-ray dosage was about 410 rep/sec and that the heavy-particle dosage was about 440 rep/sec. A dosage rate of 1 rep produces about 2.1×10^9 ion pairs/cm³ of standard air or $2.1 \times 10^9\ (93/83)(0.804/1.29) = 1.5 \times 10^9$ ion pairs/cm³ of standard water vapor.* Thus, there are formed $410(1/750)(273/301)[722 \times 2.1 \times 10^9 + 28 \times 1.5 \times 10^9] = 7.5 \times 10^{11}$ ion pairs/cm³/sec from gamma rays.

From a study of the passage of heavy particles through gases, it was concluded that the energy required to form an ion pair in water vapor was 12% less than in air (*9*). Thus there are formed $440[273/(301 \times 750)][2.1 \times 10^9][722 + (28)(1.12)(0.804/1.29)] = 7.3 \times 10^{11}$ ion pairs/sec from the heavy particles. This estimate probably should be reduced somewhat since part of the energy conveyed to heavy particles would be lost in other ways than ionization, and some of the ions (hydrogen) might not be quite as effective in promoting reaction.

The total number of ion pairs/cm³/sec has been estimated as about 1.5×10^{12}, and if this is compared with the observed rate of reaction, 1.8×10^{12} atoms/cm³/sec of nitrogen fixed, there is a yield of about unity.

Accuracy

Although the CP-3 reactor is cylindrically symmetrical and the central thimble is inserted axially, the shortness of the vertical axis causes a vertical variation in fluxes in the accessible regions. This variation is estimated as about 20% for the slow-neutron flux and 50% for the fast-neutron flux. No attempt has been made to estimate the gamma-ray-flux variations. Since some of the irradiation cans were stacked vertically, a variation would have occurred in the results.

Figure 1 shows that the small peripheral tubes are not located symmetrically with respect to the reactor; some variation, perhaps 10–20%, would be encountered in moving from one of these tubes to another. Additional variations would depend on the particular loading.

In view of the crudeness of the approximations and the possible experimental variations, it is surprising that in several cases in which an attempt was made to estimate the ionization by the methods used here, the estimated effects agree with the experimental effects to better than 50%. Thus, it is felt that the computations can be relied on to a factor of 2.

* * *

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* The fraction 93/83 is the ratio of the absorption coefficients, and 0.804/1.29 is the ratio of the densities.

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Where Does the U. S. Atomic

The Joint Congressional Committee on Atomic Energy has completed two weeks of hearings* on "the development, growth and state of the atomic energy industry." Considerable light was shed on the problems to be faced by AEC and industry in the months ahead. This is a report on the highlights of the hearings.

THE ATOMIC ENERGY ACT OF 1954 was passed for the purpose of fostering the development of an American nuclear industry. Because of the considerable powers given to AEC under the law, it is recognized that the health of the industry will be dependent to a considerable degree upon AEC's judgment in its use of these powers. Thus the Joint Committee on Atomic Energy, in its hearings required under Sec. 202 of the law, asked AEC to report on its regulatory program.

Industrial Participation

The heart of the hearings and that part of them on which perhaps the most useful information came out was the discussion of AEC's philosophy and plans regarding "opening the door" to industry.

The Joint Committee is anxious that industry be permitted to obtain licenses for nuclear activities with as few "strings" and inhibitions imposed by AEC as possible. This thinking was borne out by the JCAE chairman, Sen. Anderson (D., N. M.): "If nothing else comes out of these hearings, I hope we will settle whether we are trying to go ahead under licenses where the Government does not have to be a partner and hence able to direct this or whether they are going to let private enterprise have a shot at it first . . . If industry is left uninhibited, maybe they will get along faster than if they have to make sure that the proposal they make is one that the Government thinks is feasible. I think we could . . . find that industry has learned that it moves along pretty rapidly when it is left alone."

These comments were, in part, aimed at AEC's "power demonstration" program, under which it is felt that AEC financial support of industrial reactors would be a subsidy and would be a circumvention of the "no subsidy" section of the law, Sec. 169. This states:

"No funds of the Commission shall be employed in the construction or operation of facilities licensed under section 103 or 104 except under contract or other arrangement entered into pursuant to section 31."

Rep. Cole (R., N. Y.) felt that the "escape" clause at the end of 169 was designed, not to permit AEC to subsidize the building of reactors, but rather to permit AEC to contract for research and development work after a private reactor has been built. This, he felt, might save AEC from building unnecessary facilities.

Prices

Because the price schedule that AEC has set for special nuclear materials is classified, there was little specific discussion. But it is quite clear that subsidy by AEC via weapons prices for plutonium produced was deliberately avoided although AEC expects to pay a slightly higher price for some of the material that is usable in weapons. It is anticipated by AEC that this may result in the shutdown of some of AEC's inefficient production reactors.

The price scale apparently does not bother Consolidated Edison which says, "A tacit assumption in our thinking was that we should accept whatever charges or prices the Commission established for material used or produced in the reactor."

On the other hand, Atomic Power Development Associates (Detroit Edison group) feels that "for commercially economic reactors, the prices . . . provide no incentive." Apparently in 1954, this group had been making its plans based on plutonium prices twice as high as what the AEC finally set. Because the earnings from plutonium were expected to be about half the earnings from the total project, the cut in price has caused this group to consider seeking AEC assistance under the "power demonstration" program.

Reactor Philosophy

"The AEC's power reactor program is based on the premise that it is the Government's responsibility to advance the frontiers of knowledge in the field of reactor development," said AEC.

Allardice (JCAE staff): Would you share the criticism that was voiced by an eminent physicist that the Commission's program has yet to produce a pile that did not surpass its design criteria in performance?

Libby: I think that it is to a certain extent valid . . . It is a little bit difficult to spend millions and millions of the people's money on what you might call a real long shot, whereas you might make time in the long run by doing it, although it might be quite expensive. I think we are trying to follow an intermediate course . . .

Nichols: My own philosophy on research and development is that we should be prepared as we see any one of the approaches look promising to back it to the hilt as far as the start of the art for that particular approach warrants. We just let whatever one wins win. I think that is the only way we can approach this thing and not have a lot of opinions, and then worry about changing them.

Power Demonstration Program

Of the $75-million that AEC has asked for in its '56 budget for the power demonstration program, $50-million will be for research and development and $25-million will be for plant and equipment. The latter money will require special Congressional authorization.

On the question of the controversial April 1 deadline set for receipt of proposals under this plan, AEC General Manager Nichols said:

"If we feel we have a broad enough base where we have good proposals,

* The hearings were scheduled to be concluded during the first part of March.

Energy Program Stand Today?

we may pick out one or two of them and say let us go forward with this for the sake of getting the art going faster, but set another deadline—maybe it ought to be October 1—so that we won't try to use, unless we have astonishing results, all the money we are asking for.

"My own feeling was that probably this April 1 date should be supplemented afterward with a date like Dec. 1 of next year, so that people who have gotten a late start can come in for the second race. That is something for the Commission to decide, based on the proposals we receive."

Raw Materials

The limitation on nuclear power development is not on the availability of uranium ores or concentrates, according to AEC. Jesse Johnson, AEC's raw materials chief, said: "If we can maintain a rate of discovery on the order of that which we have had during the past four or five years, we certainly should be able to supply from domestic sources the nuclear power requirements of the U. S. for a matter of 40 years or more."

Another comment by Johnson was that "For each 1,000,000 kw of electrical capacity, about 600 tons of natural uranium would be required for the initial inventory. Following that, 50 tons of natural uranium would be required for annual replacement on the basis of a 2% burnup. . . . With a 3% burnup, which I think our reactor people feel is something that might not be too difficult, the 50 tons of annual replacement would drop to 33 tons. If the burnup was 10%, the annual requirement would drop to 10 tons."

Reactor Safeguards

Allardice (JCAE): Has the Commission exercised independent judicial scrutiny of these advices given to it [by the Advisory Committee on Reactor Safeguards]?

Nichols: Yes. Also I have talked to the reactor safeguards committee and said, "Have you really analyzed this as to what is a common-sense solution here?" It is something that I do not feel we have a happy solution to, yet, because any group that is set up to point out hazards tends to point them out.

Allardice: Do you believe that the attitude and the recommendations so far of the committee have had a deterring effect on insurance companies?

Nichols: Yes. I personally feel they have been a little too conservative . . . They do not want to be involved in a recommendation that might ultimately lead to an accident.

Industry Activities

Atomic Power Development Associates. APDA will set up a nonprofit membership corporation to build its proposed developmental 100,000-kw breeder reactor. It is expected that a plan for such a reactor will be submitted to AEC prior to April 1 as a proposal under AEC's "power demonstration" program.

Con Ed. It now appears that the world's first full-scale privately owned nuclear power plant will be built by Consolidated Edison Co. of N. Y. with 100% private money. Proposals for building a 100,000–200,000 kw reactor have been sought by Con Ed from GE, Westinghouse and Babcock and Wilcox, with the latter said to have submitted the "most attractive" offer. This offer reportedly "combines a demonstrated and conservative technique, with a substantial advance in the fuel elements, producing an over-all result that we hope will be reasonably competitive with conventional plants in our area. In consequence, we have every expectation of applying to the Commission for licenses in the near future, and we hope to do so prior to April 1."

Manpower

Based on an estimate that nuclear reactors will be producing 12-million electrical kw in 1975, AEC foresees a jump from the present 14,000 scientists and engineers working in atomic energy to 40,000. This would mean training 4,000 such new men per year instead of the present 1,500.

AEC gives "on the job" training to engineers from industry for one-year periods. Such assignments "may be as a consequence of a consultant contract, a personnel loan or other suitable arrangement." To date, 165 engineers have been so trained. At present, about 200 men from 90 different organizations are working in AEC facilities.

Comments about the industry

It is estimated by AEC that approximately 50% of the Government funds expended on the PWR will be under contracts awarded on a competitive bid basis.

BUGHER, AEC director of biology and medicine: I anticipate that over a span of 10 years or so most of the medical centers in the country would be interested in a reactor for medical purposes.

The Joint Committee inquired "about the transfers of people back and forth between the private portions of the [industrial] laboratories and the portions they are operating under contract."

NICHOLS: It is one of the things we presently have before the Commission to try to resolve, and put some better guide lines on it . . . I think you have to permit that interchange if you are going to build a healthy industry.

NICHOLS: In Oak Ridge some of the technical people feel that their reactor is getting to the point where if it is not picked up by private enterprise, maybe the Government should build it there and use the power.

NICHOLS: We have one company that already is turning out such things as control rods under an authorization. In this case it happened to be helping Canada.

NICHOLS: The purpose of the Argonne fuel element fabrication facility was not to go into the production business, but essentially to do development work for different types of fuel assemblies. We felt we needed one facility in our Government laboratories for industrial development.

DAVIS: The estimate [on the APPR] was prepared by Oak Ridge and was about $4-million . . .

NICHOLS: I personally feel that the company bidding on this [ALCO] is taking some loss on the initial reactor in the hopes that here will be future business . . . Instead of giving the price of the first one, they may give the price at which they hope to produce successive models . . . I would say that there is some basis for a statement [that the successful bidder on this contract bought it by bidding under].

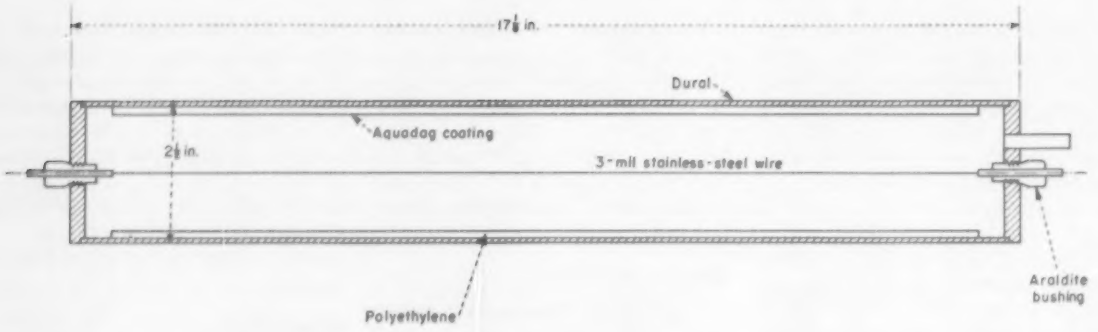

FIG. 1. Proton-recoil fast-neutron counter. Dural was used for walls to keep them light. Counter was vacuum-sealed with cold-setting Araldite (Ciba, New York, N. Y.). Space between counter ends and polyethylene permits detecting protons emerging near ends of polyethylene before they enter end walls. Counter characteristic is given in Fig. 5

Portable Survey Meter for

Problem: Need survey meter that will respond to fast or slow neutrons

Solution: Design BF_3 counter for slow neutrons and proton-recoil counter for fast neutrons so as to operate at the same voltage and to have similar counting rates, then use common high-voltage supply and counting-rate meter

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NEUTRON SURVEY METERS should have high efficiency, nondirectional characteristics, energy independence (or known energy dependence), and the ability to discriminate against gamma rays. The present instrument represents an attempt to combine these features with response to both fast and slow neutrons. A BF_3 proportional counter is used to detect slow neutrons, a proton-recoil counter to detect fast neutrons. Either counter can feed a common counting-rate meter. Proportional counters were chosen because they have good gamma-ray discrimination, are essentially nondirectional, and are small enough and have power requirements low enough for a portable instrument.

Fast-Neutron Counter

The proton-recoil counter employed in this instrument is shown in Fig. 1. The theory of its operation has been discussed elsewhere (*1–3*). Sensitivity is directly proportional to energy as shown in Fig. 2. The counting rate, C_f, is given by Eq. 7 of (*1*)

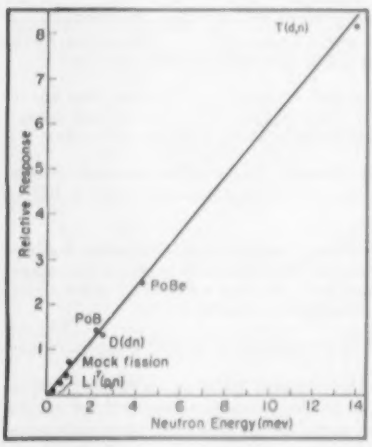

FIG. 2. Response of proton-recoil counter

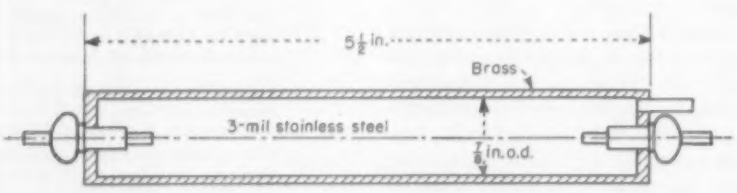

FIG. 3. BF_3 counter for slow neutrons

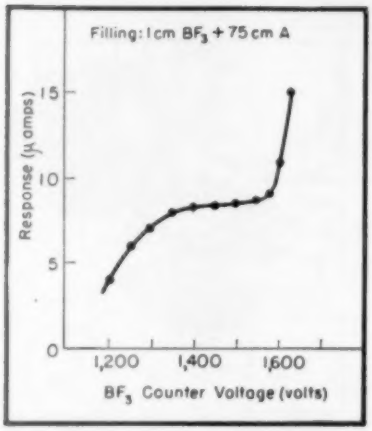

FIG. 4. Characteristic of slow-neutron counter. Note 200-v-wide plateau; it allows adjustment to recoil-counter voltage

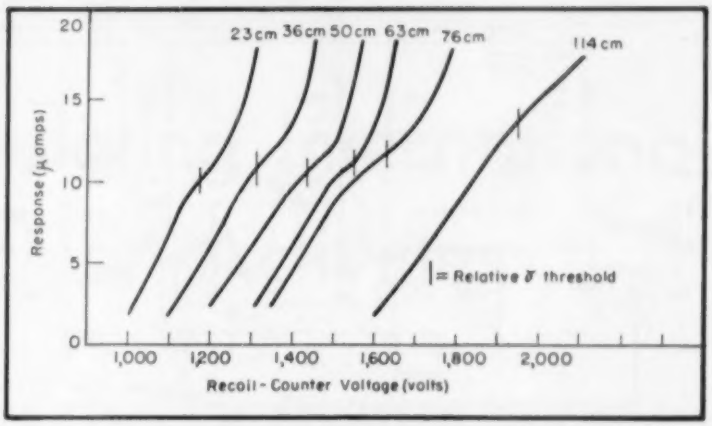

FIG. 5. Characteristics of fast-neutron proton-recoil counter. Filling gas is 96% A, 4% CO_2. Note decreased gamma-ray sensitivity (due to wall effects) as the pressure is increased

Fast and Slow Neutrons

$$C_f = 10^{-27} N_H A \int \phi_f(E) E \, dE \quad (1)$$

where N_H = number of hydrogen atoms/cm³ in wall material, A = area of hydrogenous material (cm²), E = energy of incident neutrons and $\phi_f(E)$ = fast flux per unit range of energy.

Equation 1 was used to fix the counter dimensions. It was reasonable to choose 100 Mev/cm²/sec as a full-scale reading on the most sensitive range and desirable to have approximately 5 cps correspond to this energy-flux density.

Substituting numerical values and accounting for those protons not detectable below the usual gamma-ray bias, we find the area of hydrogenous material needed is about 1,000 cm². The thickness can be chosen from Moyer's curves (*1*) and is usually taken as $\frac{1}{16}$ in. for the energy interval 0.1–20 Mev.

Slow-Neutron Counter

The BF_3 proportional counter used to measure the slow-neutron flux is shown in Fig. 3. Its counting rate is

$$C_s = \phi_s V N_B \sigma_B \quad (2)$$

where ϕ_s = slow-neutron flux (n/cm²/sec), V = active volume of the counter (cm³), N_B = number of B^{10} atoms/cm³ of counter gas, and σ_B = B^{10} capture cross section at thermal energy. (Usually shield-leakage flux is sufficiently peaked at thermal energies to allow one to assume that the thermal cross section applies over the entire energy interval measured by the boron counter.)

The presently accepted slow-neutron tolerance is around 1,500 n/cm²/sec. A practical counter should be able to measure to about 20 × tolerance and have the most sensitive range read up to a maximum of 300 n/cm²/sec.

The range of counting rate C_s should be about the same as that of C_f to simplify the electronics. Proton-recoil-counter response limits a practical survey meter with three ranges in factors of ten to an upper limit of ~500 cps.

Putting these values into Eq. 2, one realizes the product VN_B is very small. If N_B is expressed as a function of the pressure P (cm Hg), for the design specifications imposed $VP = 40$ cm⁴.

Enriched BF_3 is hardly necessary but was used because of its availability in purified form. A pressure of 1 cm Hg was used, the lowest readily measurable on our BF_3 system. This leads to the reasonable counter dimensions shown in Fig. 3.

In this simple type of counter construction it is necessary to increase V by about 20% to take care of end effects.

A pressure of 1 cm was too low for good counter operation, so the pressure was raised to 1 atmosphere with dry argon. The counter characteristic is shown in Fig. 4.

Electronics

To simplify the electronics, both counters should operate at the same voltage. From Fig. 4 an operating voltage of 1,500 v could be chosen for

Difficulties of Neutron Monitoring

Portable neutron instrumentation has not attained the development and simplicity enjoyed by other types of radiation-detectors. Neutron detectors depend upon a nuclear cross section, and therefore have inherently low efficiencies. They are usually energy-dependent as well. Attempts to overcome some of these disadvantages have met with moderate success (1–3). Usually when one condition is satisfied another must be given a secondary role or balanced by some other method.

The presence of gamma rays in all neutron fields is an additional factor affecting neutron dosimetry which must be taken into account because of the different relative biological effectiveness (RBE) of neutrons and gammas—approximately 10 for fast neutrons and 2.5 for slow neutrons.

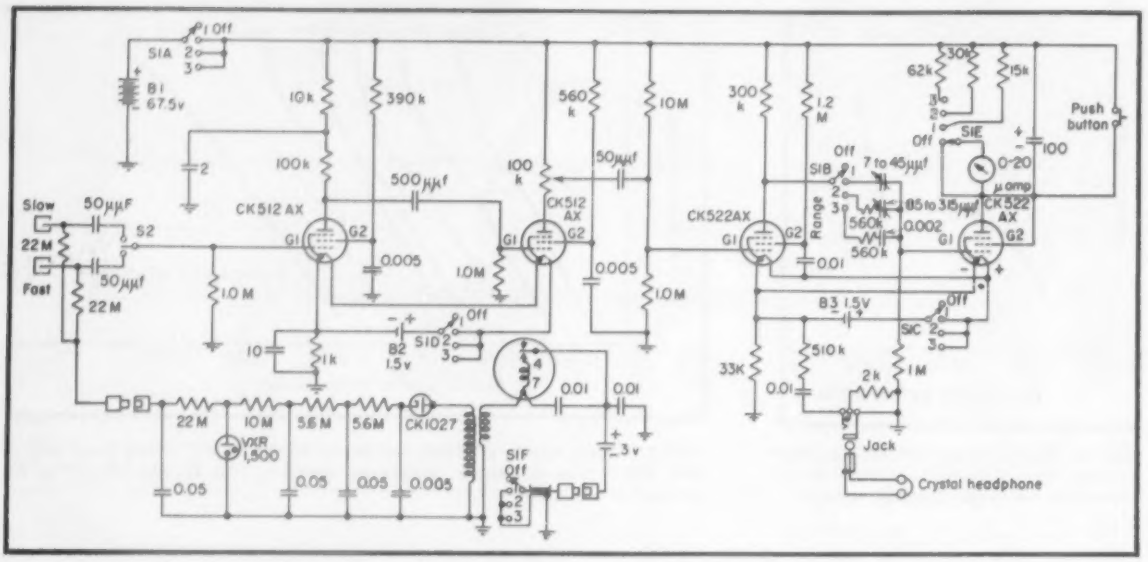

FIG. 6. Schematic of counting-rate meter and vibrator high-voltage supply. For 10-μsec-wide, 10-mv-high input pulse, counting rate drops 10% when plate battery (B1) drops to 57 v, or when multivibrator-filament battery (B2) drops to 0.9 v, or when amplifier-filament battery (B3) drops to 1.2 v

the BF_3 counter. A family of characteristic curves for the proton-recoil counter at different pressures is shown in Fig. 5. From these curves it is seen that an operating pressure of 68 cm Hg of the filling gas (96% A, 4% CO_2) allows 1,500-v operation. (Resultant decrease in gamma-ray sensitivity makes high-pressure operation desirable, but a compromise is needed to insure compatability with the BF_3 counter.)

The instrument includes the basic counting-rate meter (*3*) and vibrator high-voltage supply shown in Fig. 6. After consideration of available high-voltage supplies it was decided to use a vibrator type powered by ordinary flashlight D cells. The table on this page lists supplies investigated, giving comparative values of power consumption, weight and battery life.

Calibration and Use

The instrument is calibrated by comparing it to a known PoBe source. Typically, when 100 mr/hr of Ra gammas are biased out, the sensitivity is such that 15 Mev/cm² of PoBe neutrons will yield 1 count. The slow-neutron calibration uses a hollow concrete cube to moderate a fast-neutron source (*4*). The plateau of the BF_3 counter allows a wide range of discriminator setting, permitting the two counters to be adjusted to operate at the same voltage and amplifier gain.

Comparison of Portable High-Voltage Supplys

Vibrator model or type supply	*Battery drain (ma)*	*Battery voltage (volts)*	*Power required (mw)*	*Battery voltage at failure (volts)*	*Battery type*	*Battery life (hr)*	*Weight of supply and batteries (lb)*
UCRL	50	3	150	1.93	VS100	88	1.73
				1.94	2 D cells	58	1.43
				1.92	4 D cells	162	1.93
Victoreen* 532	95	3	285				1.37
Victoreen* 517	60	4.5	270				2.03
Nuclear† 2019	36	3.0	108				1.70
Relaxation osc., plate battery	50	1.5	500				1.63
	3.2	135					

* Victoreen Instrument Co., 5800 Hough Ave., Cleveland 3, Ohio.
† Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Illinois.

If the neutron spectrum to be measured is known well enough to approximate a mean energy, then this instrument can be used to evaluate the radiation hazard due to fast neutrons. If the slow-neutron flux is sufficiently peaked at thermal energies the BF_3 counter can be used to estimate it.

The instrument is compact and portable, weighing only ten pounds. Its high sensitivity, nondirectional characteristics, and the ability to bias against gammas make it a valuable tool in estimating the radiological hazard due to neutrons. Three ranges are provided, enabling one to read from 0–300, 3,000, or 30,000 slow neutrons/cm²/sec. The sensitivity of the fast-neutron counter is approximately proportional to energy from 0.1 to 20 Mev, and the three ranges correspond to 0–100, 1,000, or 10,000 Mev/cm²/sec.

* * *

The author is indebted to Burton J. Moyer for his contributions and frequent advice, and to Dwight Dixon and Vern Ogren for their many helpful suggestions. This work was done under the auspices of the U. S. Atomic Energy Commission.

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Regulating International Nuclear Activities

Not only does the Atomic Energy Act of 1954 specify how the Government can exchange nuclear data and materials with other nations and international bodies —it also provides the base on which the American nuclear industry can do business overseas. This article clarifies the many ramifications of the law

By Rep. W. STERLING COLE (R., N. Y.)
Chairman, 83rd Congress
Joint Committee on Atomic Energy
Washington, D. C.

SCIENTISTS SPEAK of the "expanding universe," but of more immediate concern is the "shrinking world" in which each nation must face the hard question posed by the atom: Will atomic energy be so used as to better man's lot, or will it, like an evil genie, smite down its would-be master?

On December 8, 1953, President Eisenhower addressed the United Nations and proposed that nations start to work together on the peaceful uses of atomic energy. He expressed the hope that thereby they might arrive at mutual understanding that could lead to effective control of the destructive uses of the atom. It is my feeling that the provisions of the Atomic Energy Act of 1954 relating to international aspects of atomic energy provide the basis for full implementation of the President's philosophy.

In addition, unless the international field is speedily opened up for American participation, there is a strong possibility of losing not only the international good will we now enjoy as a result of the President's magnificent offer, but also we may weaken our industrial role in the coming international atomic marketplace. Already other nations, including Great Britain, are taking strides to capture as much of the market as possible with the resources at their command.

INTERNATIONAL ARRANGEMENTS

In the Atomic Energy Act of 1946, there was a section on International Arrangements (Sec. 8). The definition of "international arrangements" included in the old Act has been carried over with but little substantive change. Under the present definition an "international arrangement" means either a treaty or an international agreement that has been approved by both houses of the Congress.

The provisions of the old Act that any international arrangement supersedes any provisions of law with which it may be in conflict is also carried over. The Atomic Energy Commission is also required to assure that its actions give the maximum effect to the policies contained in any international arrangement.

Now, of course, a treaty, by the terms of Article VI, Clause 2 of the Constitution, is the supreme law of the land, subject only to the provisions of our Constitution. Also, an international agreement approved by both houses of Congress (and necessarily approved by the President) has at least equal status as legislation. These provisions of the Atomic Energy Act of 1954, therefore, simply codify the effect of both kinds of international accords. In each, the Congress has an opportunity to examine and approve the international arrangement.

AGREEMENTS FOR COOPERATION

However, the Congress also wanted to give the President a means of dealing internationally with certain portions of the atomic energy program, without requiring him to come back to Congress for full approval of each agreement. Indeed, the Atomic Energy Act of 1946 had been amended in 1951 to permit transferring certain carefully defined areas of Restricted Data to other nations under specified conditions.

That technique was restudied and redrafted to become what, under the new Atomic Energy Act of 1954, are known as "agreements for cooperation." The technique was also expanded to cover materials and facili-

ties. Each agreement for cooperation is, however, required to lie before the Joint Committee for 30 days while Congress is in session. Agreements for cooperation are, in effect, less formal methods of dealing with international affairs than international arrangements and do not require Congressional approval.

I should point out that agreements for cooperation are basically designed to be bilateral agreements, each with a single nation. There are two exceptions—the regional defense organization receiving Restricted Data relating to weapons under Sec. 144b, and any international atomic pool entered into in accordance with Sec. 124.

Procedures—Section 123

The procedures involved in agreements for cooperation are found in the provisions of Sec. 123, entitled "Cooperation with Other Nations." Section 123 does *not* cover the substantive parts of agreements; rather it deals only with the procedural aspects of those agreements—the steps that must be taken to make the agreements effective. In essence these steps result in a sheaf of three papers that must come before the Joint Committee before the agreement can become effective.

Proposed agreement. The first paper in the sheaf is the proposed agreement for cooperation; this must meet certain statutory requirements:

1. The terms, conditions, duration, nature and scope of the cooperation must be set forth.

2. A guaranty by the cooperating party that security safeguards and standards as set forth in the agreement for cooperation will be maintained must be included.

3. A guaranty by the cooperating party that any material to be transferred pursuant to the agreement for cooperation will not be used for atomic weapons, or for research on or development of atomic weapons, or for any other military purpose, must be stated.

4. A guaranty by the cooperating party that any material or any Restricted Data to be transferred pursuant to the agreement for cooperation will not be transferred to unauthorized persons or beyond the jurisdiction of the cooperating party, except as specified in the agreement for cooperation, must be included.

Commission recommendation. The second paper in the sheaf is the recommendation of the Commission, or of the Department of Defense as the case may be, on the proposed agreement. The statute carefully does not specify which department or agency of the Government is to negotiate any particular agreement. It was thought presumptuous for the legislative branch to seek to tell the President which department or agency he must use in conducting international negotiations. This is a change from the old Act, which required that it be the Commission that entered into any agreement.

However, it was thought that there should at least be a statutory requirement for either the Commission or the Department of Defense, whichever is proper, to make its recommendation with respect to the proposed agreement. This recommendation is not absolutely binding upon the President, and he might approve the agreement and send it on through the balance of the steps despite an adverse recommendation.

The old law made approval by the Commission a statutory requirement, and even required that Commission approval be unanimous. The new law brings out the advice of that agency or department with special competence in the particular field involved in the proposed agreement, but it leaves to the President, who has the basic constitutional responsibility for international affairs, the final determination in the executive branch. If he desires to consult the National Security Council, he is free to do so, but this is not required, as under the old Act.

I should state here that the only instance in which the statute requires the Department of Defense to make its recommendation is in the case of the proposed communication of Restricted Data dealing with weapons pursuant to Section 144b.

Presidential approval and determination. The third paper in the sheaf is the determination of the President that the performance of the proposed agreement will promote, and will not constitute an unreasonable risk to, the common defense and security.* He is required to make this determination in writing after he has received the proposed agreement, together with the recommendation of the Commission or the Department of Defense. Under the old Atomic Energy Act of 1946, the President was required to find "that the arrangement would substantially promote and would not endanger the common defense and security of the United States."

The President, again as the person charged with the responsibility for deciding who shall handle the actual relationships with other nations, must authorize the execution of the proposed agreement.

Joint Committee scrutiny. After the President has made his determination, the sheaf of three papers is then required to lie before the Joint Committee for 30 days while Congress is in session. This requirement is essentially for informational purposes. The Joint Committee has no power to approve or disapprove any specific agreement. However, if Joint Committee members find that there is anything in the agreement with which they have serious disagreement, there are several courses open to them:

1. They can discuss the matter with the President, the Commission, the Department of State and the Department of Defense to try to persuade them to the views of the Joint Committee members.

2. They can, in most instances foreseen, discuss the matter on the floor of the House and the Senate and raise public issue over the disputed matters.

3. They can introduce legislation to prevent consummation of the agreement.

4. They can attach conditions to other legislation, such as appropriations, which will prevent spending money under the agreement, or will prevent or hedge the operations under the agreement.

The Joint Committee does not have the authority to waive the 30-day period in the case of agreements for cooperation, as it does in connection with the determinations of new material as special nuclear material (Sec. 51), or as source material (Sec. 61), or in connection with long-term contracts for electric utility services (Sec. 164). Therefore, the Administration must come forward with any proposed agreements for cooperation sufficiently early in each session of Congress for the statutory period

* At this point I should draw attention to the definition set forth in Sec. 11g: "The term 'common defense and security' means the common defense and security of the United States." The phrase is not intended to mean the common defense and security of the United States and the other country. That meaning is embodied in the phrase "mutual defense and security" as used in Sec. 144b.

Misconceptions

Many misconceptions exist as to the purposes and extent of the international provisions of the Atomic Energy Act of 1954. Perhaps what I have written in this article will dispel them. If not, let me make clear:

1. Activities abroad are not licensed; it is only activities over which this country has control which are licensed; the activities abroad are authorized by appropriate means;

2. There is a distinction between an authorization and a license;

3. No attempt was made to regulate the construction or ownership of facilities abroad, except through the authorization features of Sec. 57a(3); this merely regulates the contributions to that ownership or construction over which the United States has any control.

4. No attempt has been made to regulate "interstate commerce outside of the U. S."

to elapse before Congress adjourns. (Early drafts of the Atomic Energy Act of 1954 carried the right of the Joint Committee to waive, but the provision was dropped by the Joint Committee because it was felt that the proposal to exercise such a waiver in international areas while Congress was out of session was an unwarranted assumption by the Joint Committee of responsibilities that properly belong to the whole Congress. This is not so in the other three instances, and waiver authority is therefore specifically granted.)

All of these steps are devised with an eye toward permitting as much international exchange as possible, and, at the same time, seeing that there is adequate control over the sensitive items of materials and information.

Substantive Aspects of Agreements for Cooperation

The new Atomic Energy Act of 1954 incorporates the applicable controls respecting international problems in the same chapter that includes controls on domestic uses. The controls are imposed on materials, facilities and information.

Materials. The provisions of the new Atomic Energy Act relating to international transfer of materials under agreements for cooperation are incorporated in Sec. 54 for special nuclear materials, in Sec. 64 for source materials, and in Sec. 82a for by-product material. The provisions are all worded identically:

> "The Commission is authorized to cooperate with any nation by distributing special nuclear (source) (by-product) material and to distribute such special nuclear (source) (by-product) material pursuant to the terms of an agreement for cooperation to which such nation is a party and which is made in accordance with section 123."†

I should draw attention to one other section with respect to special nuclear materials. That is Sec. 57a(3), which in part says that it is unlawful for any person to

> "(3) directly or indirectly engage in the production of any special nuclear material outside of the United States except (A) under an agreement for cooperation made pursuant to section 123, or (B). . . ."‡

Since special nuclear material is so vital to the production of atomic weapons, it was thought essential to the common defense and security of this country that no one in this country should be permitted to go abroad and help any other country, either directly or indirectly, to produce special nuclear material. However, it was recognized that activities of this kind involving Restricted Data might be desirable as part of the enlarged program for international coopreration. Therefore, such activities are permitted where they are done under an agreement for cooperation.

Facilities. The Commission is authorized to grant licenses to persons within this country to export facilities for the utilization or production of special nuclear material. The right to grant such a license with respect to facilities that the Commission has found to be of practical value is set forth in Sec. 103a; for research and development facilities the authority is contained in Sec. 104d. In either case, the export must be undertaken pursuant to an agreement for cooperation, except that certain component parts of such facilities, which do not involve Restricted Data, may be exported under simple license granted by the Commission.

The limitations on export are further clarified by the words of Sec. 103d and Sec. 104d, which expressly prohibit the Commission from granting any license under those sections to any person for any activity not under or within the jurisdiction of the United States except under an export license pursuant to an agreement for cooperation, with the sole exception of component parts (Sec. 109) that do not involve Restricted Data. It was intended that these sections operate as follows: the United States might enter into an agreement for cooperation with another nation, requiring the export to that nation of, for instance, a reactor. The firm in this country from whom that nation desires to purchase the reactor must then obtain a license to export that reactor pursuant to terms of the agreement and rules and regulations promulgated by the Commission.

I see no undue complications in this method of procedure. The rights of the exporter within this country are established by rules and regulations. The rights of the importer within the country receiving the facilities are, of course, to be determined by the laws of that country. Both are subject to the terms of the agreement for cooperation.

Information. Section 144 permits the President to authorize the Commission and the Department of Defense to communicate certain specific kinds of information to other nations. The Commission is authorized to communicate to other nations, pursuant to an agreement for cooperation, Restricted Data on the peaceful uses of atomic energy. The Department of Defense is likewise authorized to communicate pursuant to an agreement for cooperation, certain Restricted Data relating to the external characteristics of weapons. In either case, however, the communication must be by the Government or an authorized agent,

† Both source and byproduct materials can be exported under license even though no agreement for cooperation has been entered into between the United States and the recipient nation. These are discussed in later sections.

‡ Subsection 57a(3)(B), which does not involve Restricted Data, will be discussed later.

and, in view of the establishment of a "gray area" of information relating to peaceful uses of atomic energy, perhaps further statutory techniques will have to be devised for the less sensitive areas of information. However, there is nothing in the new law prohibiting the Commission from using a contractor to communicate Restricted Data under Commission supervision.

Information on peaceful uses. Under the terms of Sec. 144a, the Commission can be authorized by the President to transmit to another nation information generally relating to the peaceful uses of atomic energy, pursuant to the terms of an agreement for cooperation. The subject matters authorized to be communicated are: (a) refining, purification, and subsequent treatment of source material; (b) reactor development; (c) production of special nuclear material; (d) health and safety; (e) industrial and other applications of atomic energy for peaceful purposes; and (f) research and development relating to the foregoing.

To be sure that sensitive information on how to construct atomic weapons is preserved, the section expressly prohibits communication of Restricted Data relating to design or fabrication of atomic weapons. Areas of communication have been broadened in the new Act *vis-à-vis* the former by the inclusion of the fourth and fifth items—health and safety, and industrial and other applications of atomic energy for peaceful purposes.

Any such agreement for cooperation has to go through the procedural steps set forth in Sec. 123.

Information on weapons. Under Sec. 144b, Restricted Data needed for mutual defense planning, for training of personnel in use of and defense against atomic weapons, and for evaluation of the atomic-weapon potential of possible enemies can be transmitted to another nation or to a regional defense organization. For the first time, the President can authorize the Department of Defense, with the assistance of the Commission, to reveal the external characteristics of atomic weapons, including the size, weight, shape, yields, and effects and systems employed in delivery or use.

To be sure that this grant did not reveal the innermost secrets of our weapons, disclosure of Restricted Data that relates to or reveals the design or fabrication of such weapons is prohibited. Other limitations are that the nations or organizations receiving information must be making a continual substantial and material contribution to the mutual defense and security.

One aspect of the Sec. 144b provisions deserves special mention. The regional defense organization to which such restricted data may be communicated must be one in which we are involved in the mutual defense and security pursuant to an international arrangement. Hence, it is only those regional defense organizations that this country has joined pursuant to a treaty (or to an international agreement that has been approved by both houses of Congress) that are eligible to receive information under this section.

INTERNATIONAL ATOMIC POOL

When the President sent his legislative proposals to the Congress, he specifically stated that legislation enabling an international atomic pool would be submitted at a later time. However, the Joint Committee and the Congress chose to go further and express general legislative approval of the President's pool plan.

Some members felt that the international atomic pool should be treated just like a nation, and they desired to permit agreements for cooperation with the pool in just the same way that agreements for cooperation are permitted with another nation. The members who felt this way based their opinion on the adequacy of the provisions for the protection of the materials and Restricted Data already written into the law.

On the other hand, there were members who, while generally favoring the international atomic pool, wanted to retain Congress's right to examine specific details of any such proposal and to approve or disapprove of the specific arrangements. They thought that the pool plan was too indefinite to warrant a blanket Congressional approval of our participation at this time.

The provisions finally incorporated in the Atomic Energy Act of 1954 constitute a combination of both views. They draw their pattern from the provisions for the communication of Restricted Data to regional defense organizations under Sec. 144b. Thus, Sec. 124 provides that the international atomic pool must first be set up by an international arrangement, which, as has been pointed out previously in the case of regional defense organizations, requires specific Congressional approval. However, once the international atomic pool is established, cooperation with that pool can be accomplished under the statutory framework for agreements for cooperation. For example, the international pool might first be established only to disseminate the classes of Restricted Data authorized to be communicated by Sec. 144a. Later on, it might be found desirable to expand that scope to include the transfer of materials and facilities. Under the law that expansion could be accomplished without requiring full formal Congressional approval all over again, by using the less formal "agreement for cooperation" route. Suppose, further, that the provisions of Sec. 144a should later be enlarged to include other areas of Restricted Data, then again that extension could be accomplished with respect to the international atomic pool by a further "agreement for cooperation."

Now let me analyze the exact language of Sec. 124. That section starts by providing:

> "Sec. 124. International Atomic Pool.—The President is authorized to enter into an international arrangement with a group of nations providing for international cooperation in the nonmilitary applications of atomic energy. . ."

Of course, the right of the President to negotiate treaties or executive agreements that are approved by Congress and hence become law in this country does not flow from any Congressional grant of power. That power flows from the Constitution. The provisions of any such international arrangement, under the terms of Sec. 121, supercede the provisions of the Act. Hence, if Congressional approval is received in the appropriate manner, the President will be enabled to set up an international atomic pool based on any principles he deems desirable.

Sec. 124 continues:

> ". . . and he may thereafter cooperate with that group of nations pursuant to sections 54, 57, 64, 82, 103, 104 or 144a . . . provided, however, that the cooperation is undertaken pursuant to an agreement for cooperation entered into in accordance with section 123."

Thus, the President might establish the whole program for the international pool at once, if he so desired. He might also only establish a small part of the plan, leaving the remainder to be implemented under agreements for cooperation.

I believe that, giving due weight to all the important considerations involved in establishing this new and fine idea of an international atomic pool, the international sections fairly and adequately meet the present situation.

OTHER CONTROLS

While agreements for cooperation provide the main basis for permitting those who are subject to the provisions of the Atomic Energy Act of 1954 to participate in activities abroad, there are still other provisions on which I should comment.

Production Abroad

The provisions under which anyone can directly or indirectly engage in the production of special nuclear material abroad are set forth in Sec. 57. Under the provisions of Sec. 57a(3)(B), the Commission may permit such direct or indirect production:

> ". . . (B) upon authorization by the Commission after a determination that such activity will not be inimical to the interest of the United States."

The old Atomic Energy Act of 1946 had a flat prohibition against any such participation in the production of special nuclear material abroad. This prohibition was thought so broad as to prevent the giving of unclassified lectures on the production of special nuclear material, or even on nuclear physics. It had also been interpreted by some as prohibiting the advertising abroad of unclassified equipment used in connection with reactors.

While such activities could conceivably prove harmful to the interests of the United States, many of these activities can do no harm, and might generally help create international good will and encourage American industry to enter the international market. Therefore, the Commission was given the authority to permit the direct or indirect participation in the production of special nuclear material abroad when it found such activity would not be inimical to the interests of the U. S.

The Commission is given permission to issue authorizations instead of licenses for this type of activity because of the differences in the locations of the activities. A Commission license only extends to activities within the jurisdiction of the United States. It not only permits the grantee to engage in the proposed activity, but it cannot be overruled by any other agency of the United States (except on appeal to the courts in a contested case). An authorization by the Commission means that insofar as the Government of this country is concerned, a person subject to its laws is permitted to engage in the specified activity abroad, but whether the laws of the nation where the activity will be conducted will permit such an activity is another matter. It is possible that they might prohibit it altogether.

Industry's Role

" . . . with respect to the furnishing of equipment, facilities, and materials (other than special nuclear materials), United States industry will play a major role in implementing agreements for cooperation . . .

" . . . It was the intention of the Commission that all agreements for cooperation with other governments shall provide for industry to supply equipment, facilities, services, and materials (other than special nuclear materials) to the extent that such activities fall within the scope of the particular agreement."

—AEC testimony before Joint Committee, Feb. 4, 1955

Source Material

While the Commission is authorized to distribute source material abroad pursuant to an agreement for cooperation, it may also so distribute source material upon a determination that such activity will not be inimical to the interests of the United States (Sec. 54).

Source materials are not as sensitive as special nuclear materials, and hence the statutory control need not be as rigid. Thus, any person may be licensed to export such materials if, in the opinion of the Commission such export will not be inimical to the common defense and security or the health and safety of the public.

Byproduct Material

With respect to byproduct materials, the Commission has similar leeway. In addition to being allowed to distribute byproduct materials abroad pursuant to an agreement for cooperation (Sec. 82a), the Commission has two other alternatives at its command.

1. It can authorize distribution of byproduct material outside the United States upon application therefor except where such distribution would be inimical to the common defense and security. In permitting any distribution abroad, the Commission is required to follow the same standards as it follows in distributing the material within the United States. This provision is designed to make the Commission treat all persons receiving such material on the same basis without preference one way or the other.

2. The Commission can also issue licenses to others to distribute the material outside of the United States, although such licenses must be issued to the distributor on the same basis as it would issue a license to that distributor for distribution within the United States. However, the Commission is given no authority over the prices that the distributor may charge for the material.

Component Parts

In addition to permission to license the export of component parts of facilities outside of the United States pursuant to an agreement for cooperation, the Commission is also permitted to issue licenses for the export of component parts if the Commission determines that each such export will not constitute an unreasonable risk to the common defense and security.

* * *

It has been said that the Commission will have to construe the new law imaginatively to foster healthy private international atomic relationships. But I believe that success of the international regulations outlined in this article will depend only on the sympathetic reading of the precise statutory provisions contained in the Atomic Energy Act of 1954. This applies not only to the Commission, but also to those who have to deal with the Commission in the international field.

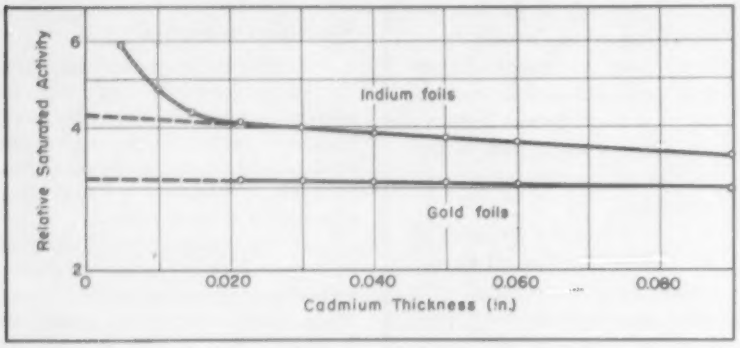

FIG. 1. Attenuation of epicadmium neutrons by cadmium covering

Correction Factors for Cd-Covered-Foil Measurements

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Cadmium-covered foils are commonly used in neutron-flux-measuring experiments to determine the flux above the cadmium cut-off point, i.e., about 0.4 ev. In conjunction with bare foils, they may also be used to obtain the thermal flux, or the flux below the cadmium cut-off.

A correction factor is frequently used to account for the attenuation of the epicadmium neutrons by the cadmium. A method of measuring this factor described by Kunstadter (*1*) consists of irradiating cadmium-covered foils with different thicknesses of cadmium covers and plotting their activities versus thickness on semilog paper (Fig. 1). The extrapolation of the straight-line tail of the curve to zero cadmium thickness permits an evaluation of the customary correction factor, which is the extrapolated activity at zero thickness divided by the activity at any given cadmium thickness.

Tittle (*2*) gives a list of the results of several experimenters who have measured this same factor with indium foils. The divergency of these results is attributed by Tittle to differences in foil thickness, but may be due to the variety of sources, media, and foil sizes. It was felt that a measurement of the correction factor under the conditions met with in foil exposures at this laboratory would be desirable. In addition, this presented an opportunity to make consistent measurements while varying parameters such as foil size, thickness, and cadmium ratio.

Description of Experiment

The cadmium-covered foils were exposed in groups of five or six by placing them on a rotating aluminum disk that was inserted into one of the removable graphite stringers of the North American Aviation water-boiler reactor. The disk, approximately 10 cm in diameter, is chain driven at about 20 rpm to eliminate any effect of positioning on the foils.

Runs were made with the disk in two positions: (1) in the center of the stringer, and (2) about 30 in. from the center. The cadmium ratios for 0.005-in.-thick indium foils at these two points were about 6 and 16, respectively. When the foils were in the center of the stringer, they were separated by about 2 in. of graphite from the edge of the spherical core of the reactor.

Cadmium covers 0.005–0.090 in. thick were used with the indium foils, and 0.020–0.090 in. thick with the gold foils. All foils were counted in each of three to five end-window beta counters. Statistical counting accuracy of about 0.1% was obtained in most cases.

As a preliminary check, the epicadmium flux perturbation was investigated by measuring the effect of other nearby cadmium boxes on the cadmium-covered foil activity. This was done by comparing the activity of a cadmium-covered foil both with and without other cadmium boxes in the vicinity. No effect was detected.

Although of secondary importance, the flux perturbation below cadmium cut-off caused by the cadmium boxes was checked to determine whether the thermal flux in this region would be seriously affected. Several bare indium foils were exposed on the disk along with a 0.090-in. cadmium box. The resulting thermal-flux depression, as indicated by Fig. 2, is evidently too small to have a significant effect on the measurements, since the thermal-neutron activation is a small correction to cadmium-covered foil measurements.

Results

A typical curve of foil-saturated activity versus thickness of cadmium covering is shown in Fig. 1. As may be seen, the points above 0.030-in. cadmium thickness lie along a straight line, which represents the attenuation of the epicadmium neutrons. The ratio between the relative activity when extrapolated back to zero cadmium thickness and the relative activity at a given cadmium thickness provides a correction factor, F_{Cd}, so that

$$A_B^{epi\text{-}Cd} = A_{Cd}^{\tau} F_{Cd} \qquad (1)$$

where $A_B^{epi\text{-}Cd}$ is the corrected epicadmium activity or the activity of a bare foil due to epicadmium neutrons, and A_{Cd}^{τ} is the total or measured activity of cadmium-covered foils.

Values of F_{Cd} are given for indium and gold foils in the table. Values for 0.040-in. cadmium permit comparison with earlier work. An error of $\pm 1\%$ had been estimated for our values of F_{Cd}, although the consistency of the data is considerably better than this. The new values differ by more than the estimated error from Kunstadter's value of 1.150; however, within the limitations of our experiment, variation in foil thickness, foil area, or cadmium ratio do not seem to account for this difference.

Thermal-Neutron Leakage

For cadmium covers below about 0.030-in. thickness, an additional small correction should be made due to the

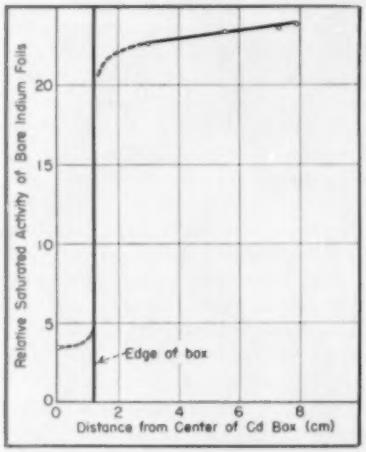

FIG. 2. Depression of bare-indium-foil activity in vicinity of cadmium box with 0.090-in.-thick walls

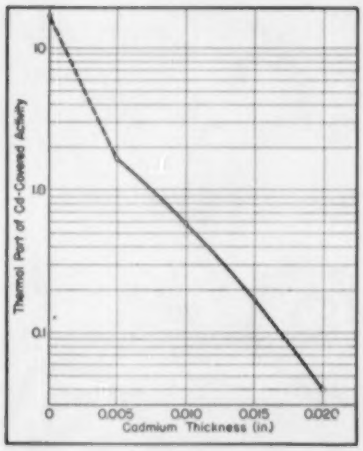

FIG. 3. Thermal-neutron activation of cadmium-covered indium foils

leakage of thermal, or "subcadmium" neutrons. To evaluate this, the straight-line portion of the curve for indium foils (Fig. 1) was subtracted from the total activity; the result is shown in Fig. 3. The point at zero cadmium thickness is obtained from a bare-foil measurement. The fact that the curve does not seem to approach this point may be because, for structural reasons, the amount of cadmium in the edges of the boxes was not proportional to top and bottom thicknesses. To a reasonable approximation, however, the neutrons separate into two groups, epicadmium and thermal, each being attenuated in an exponential manner.

To obtain the true epicadmium activity for thinly covered foils, the thermal-neutron activation of cadmium-covered foils, A_{Cd}^{th}, which is represented in Fig. 3, should be subtracted from the total cadmium-covered activity, A_{Cd}^{T}, before the correction factor, F_{Cd}, is applied

$$A_B^{epi\text{-}Cd} = (A_{Cd}^{T} - A_{Cd}^{th})F_{Cd} \qquad (2)$$

A_{Cd}^{th}, the thermal part of the cadmium-covered foil activity, is proportional to A_B^{th}, the thermal-neutron activation of a bare foil, so that

$$A_{Cd}^{th} = XA_B^{th}$$

where X is a proportionality factor dependent only on the cadmium thickness. From the data of Fig. 3, X is 0.002 for a cadmium thickness of 0.020 in. Equation 2 can thus be written

$$A_B^{epi\text{-}Cd} = (A_{Cd}^{T} - XA_B^{th})F_{Cd} \qquad (3)$$

Since the thermal part of the bare-foil activity is the difference between the total bare-foil activity and the epicadmium part of the bare-foil activity

$$A_B^{th} = A_B^{T} - A_B^{epi\text{-}Cd} = A_B^{T} - (A_{Cd}^{T} - XA_B^{th})F_{Cd}$$

Solving for A_B^{th}

$$A_B^{th} = \frac{A_B^{T} - A_{Cd}^{T}F_{Cd}}{1 - XF_{Cd}} \qquad (4)$$

and, conversely, the epicadmium part of the bare foil activity is

$$A_B^{epi\text{-}Cd} = A_B^{T} - A_B^{th} = F_{Cd}\frac{A_{Cd}^{T} - XA_B^{T}}{1 - XF_{Cd}} \qquad (5)$$

With the constants F_{Cd} and X known, Eqs. 4 and 5 give accurate expressions for the foil activity due to thermal neutrons and foil activity due to epicadmium neutrons in terms of a bare and a cadmium-covered foil measurement. Since X is usually too small to be significant, Eq. 1 can be used instead of Eq. 5. However, for 0.020-in. or thinner cadmium, X may be important, in particular for high cadmium ratios where A_B^{T} is much larger than A_{Cd}^{T}.

* * *

This work is based upon studies conducted for the U. S. Atomic Energy Commission.

Correction Factors for Use with Cadmium-Covered Foils

Researcher	*Foil weight (mg/cm²)*	*Foil size (cm)*	*Medium*	*Cd ratio (approx.)*	*Correction factor for 0.040-in. Cd*
Indium Foils					
Walker (*3*)	3.59	2 × 3.1	Water	10	1.077
Dacey, *et al.* (*4*)	58.8	3.02 (dia.)	Water and solutions	10	1.120
Rush (*5*)	93.5	4 × 6.35	Water	10	1.123
Kunstadter (*1*)	94.5	4 × 6.35	Graphite	50	1.150
Martin	94	1.00 × 1.00	Graphite of WBNS	6	1.098
	88	1.00 × 1.00	Graphite of WBNS	6	1.094
	69	1.00 × 1.00	Graphite of WBNS	6	1.09
	29	1.00 × 1.00	Graphite of WBNS	6	1.09
	88	1.00 × 1.00	Graphite of WBNS	16	1.095
	88	0.20 × 1.00	Graphite of WBNS	6	1.10
Gold Foils					
Martin	238	1.00 × 1.00	Graphite of WBNS	6	1.02
	225	0.02 × 1.00	Graphite of WBNS	6	1.02

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Specific-Activity Determination with Beta and UV-Photon Counter

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Unequivocal determination of the specific activity (radioactivity per unit weight) of a compound initially present in admixture with other compounds is a common problem in radioisotope tracer studies. Conventional criteria of chemical purity may fail to reveal minor constituents that represent extreme contamination from a radiochemical standpoint. Such contamination is generally obvious, however, if the constancy of isotope concentration of the compound in serial fractions of a separating system of high resolving efficiency be evaluated quantitatively. Papergrams developed with appropriate chromatographic solvents or electrophoresis are, after drying, immobilized separating systems with deposits that can usually be measured *in situ*.

Each compound in a developed papergram is characteristically distributed through the paper as a nearly circular spot or as a line parallel to the baseline (*1, 2*), depending on how the mixture was applied to the paper. The distance across the circle or line, along the straight lane of transit, is usually 5–50 mm, and it is this distance that is appropriately subdivided for measurements. Serial fractions may be delineated by a lead or platinum mask with appropriate aperture for beta radiation from compounds in the paper and light radiation transmitted from a lamp through the paper. If the radioactive compound under study absorbs ultraviolet light, or can be caused to do so by a reaction in the paper, all measurements for evaluating radiochemical purity and determining specific activity are easily made by using a counting tube with gas phase sensitive to beta radiation and cathode sensitive to ultraviolet photon radiation. The equipment used is shown in Figs. 1–4.

FIG. 1. Beta-photon counter, as single unit, measures radioactivity and light absorption at same area of papergram. Photovolt 52A transmission-density unit for chromatograms contains 4-watt low-pressure mercury lamp and light aperture with shutter in platform below papergram. Polyethylene-coated lead mask aids in placing paper and defines effective aperture for transmitted quantum radiation and emitted beta radiation. Vertically adjustable hollow arm with sliding filters of beta-opaque quartz and ultraviolet-opaque gelatin film supports detector. Since photon counting rate may be high over blank paper areas, G-M tube is plugged into cathode follower to maintain uniform pulse height. Transparent plastic tube supplies helium-butane (98.7:1.3) counting gas. Counting-rate meter has 4 ranges of 5, 50, 500, and 5,000 cps, full scale, corresponding to densitometry transmission readings of 0.1, 1.0, 10, and 100% and optical densities of 3.0, 2.0, 1.0, and 0.0

FIG. 2. Modified unit uses separate beta and photon counters attached to scaler and ratemeter, respectively, for measuring same masked area of samples of low-intensity or low-energy betas

Determining Radioactivity

Procedures used for measuring radioactivity of compounds in chromatograms are similar in many respects to those developed by other investigators (*6*).

Chromatograms are prepared for measurement by ruling a straight line along the lane of transit. If all compounds are invisible, centering the guide line is aided by preliminary rapid scanning for ultraviolet absorption (*2*) or radioactivity. The line is graduated with ruler and pencil at appropriate intervals. The rectangular aperture in a mask of polyethylene-coated lead is centered over the area of interest by aligning the ruled line with lines inscribed on the mask. Beta radiation traversing the aperture is measured with one of the units shown.

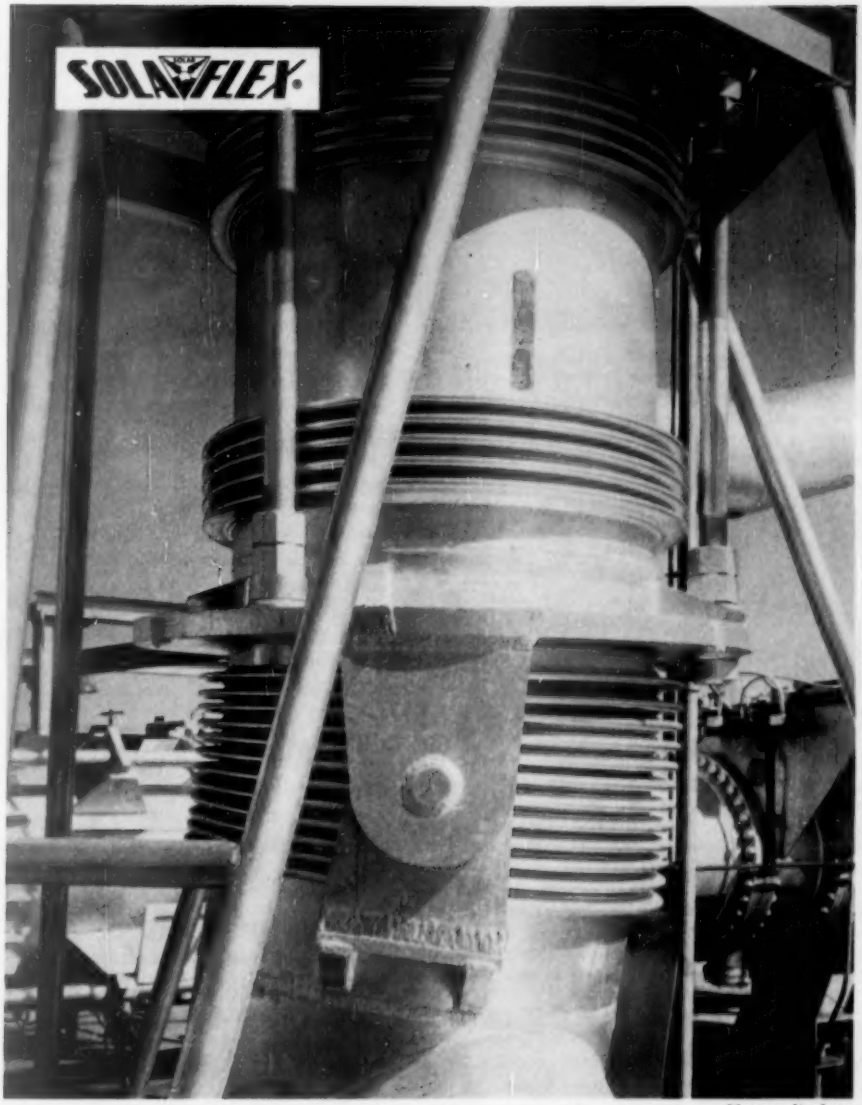
The most suitable measuring assembly (Figs. 1–3) is selected on the basis of beta-emission characteristics of the sample, its distribution in the paper, and objectives of the investigation. Subjective errors and random counting errors are minimized by using a continuous recorder with the ratemeter. Alternatively, a scaler is employed.

Chromatographic paper is eminently suitable for measuring beta emitters with an E_{max} of 0.1 Mev or higher. Precision of measurement is comparable to the best that can be attained with samples in planchets. Where the specific activity is to be determined as the average of multiple values found in multiple areas, individual areas may be counted with relatively low statistical precision. Net standard deviations of the radioactivity measurements used to compute specific activity in Figs. 5 and 6 are 1% and 3%, respectively.

Determining Amount

Applying the uv-photon-counting-rate meter, in evaluating the amount of a light-absorbing compound in paper, differs little from application of conventional photometers operating on a current-metering basis (*7*). Differences in technique take advantage of the phenomenal sensitivity of the photon counter and, where useful, a selective aspect of the sensitivity that permits limiting response to light of wavelength absorbable by the compounds under investigation. The new techniques are described in a detailed report (*2*) and were designed specifically for evaluating the amount of a compound per unit area of paper as required in specific activity determination.

Areas along the graduated line are set off by the same lead-mask aperture employed in the radioactivity measure-



Marquardt photo

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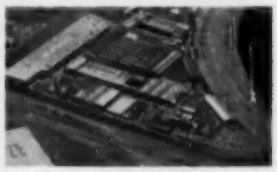

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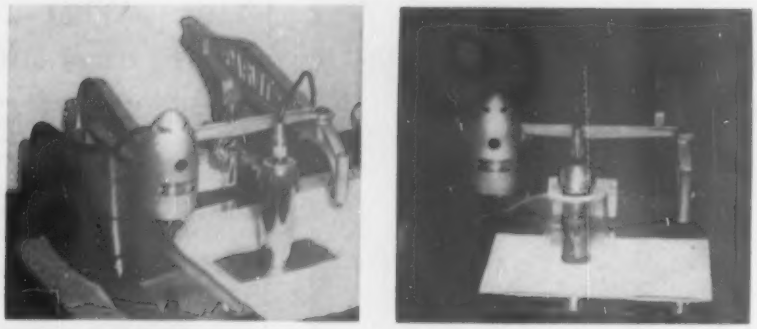

FIG. 3. With most papergrams, measured area can be satisfactorily reproduced by following graduations ruled on paper with pencil. To measure weak beta activity, one can use end-window counter (left) or windowless gas-flow counter (right) manipulated with tracing machine. Flow counter is same as in Fig. 4 with window removed and enclosed in transparent plastic chamber for continuous preflushing; like other flow counters (3), it provides extreme sensitivity for measuring ionizing radiation

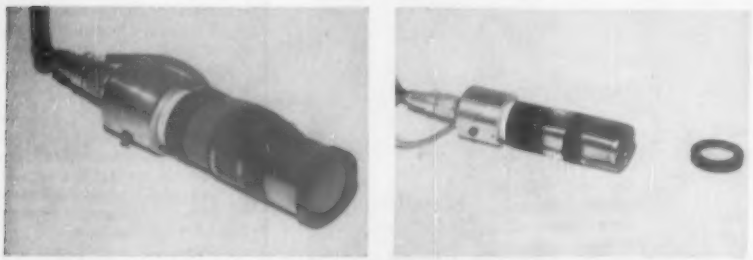

FIG. 4. Beta-photon counting tubes are Tracerlab TGC-2 tubes modified for entry of photons and betas (2) and for continuous flow of counting gas, which appears to give greater stability than earlier photon counters (4, 5). Stainless-steel cathode provides greater sensitivity in far ultraviolet than does ordinary chromatographic electronic photometer (2); sensitivity is increased thousandfold by inserting copper, aluminum or platinum cylinders so as to contact spring cathode lead with (left) or without (right) steel cathode. Copper-cathode spectral sensitivity (2) terminates at long-wave limit of 263 mμ, permitting isolation of 254-mμ mercury line of commercial germicidal lamps. Of greater sensitivity and almost the same quantum specificity are carbon cathodes of Tracerlab TGC-2 tubes. Aluminum cathode, 210–400 mμ sensitivity, is used with ultraviolet monochromator

ment. For all but the most rigorous requirements, the area may alternatively be delineated by an identical aperture in the platform of the light box supporting the chromatogram. The lamp is turned on and intensity adjusted so that the ratemeter is zeroed for density at a blank area of the paper. A full-scale deflection on the least sensitive scale, i.e., 5,000 photons per sec with the unit of Fig. 1, is conveniently chosen for zero density. The papergram is advanced from one graduation to the next, and density values recorded on a continuous recorder or manually on graph paper. Amount of a known absorbing compound corresponding to a measured optical density is determined by reference to an empirical concentration-density curve.

While the absorption of monochromatic light by compounds in chromatograms is reproducible to within 1 or 2% mean deviation, the linear density-concentration relationship typical for absorbers in transparent media does not obtain in a medium of paper. A more complex function of optical variables (8) is related linearly to concentration (9).

Specific Activity

Radiochemical contamination of a light-absorbing compound is usually apparent immediately, as the radioactivity curve is plotted, and compared with the density curve (Fig. 5). Actual calculation of specific activity of a compound in successive areas provides, however, the most crucial test for radiochemical purity. To do this, the cpm for each area of paper containing compound is divided by the amount of compound in the area. With great care and special chromatographic technique, precision of about 2% mean deviation results for specific activity values at successive areas of a paper chromatogram occupied by a pure, radioactive, light-absorbing compound. Precision of ±5% mean deviation results without special techniques or corrections. Conformance with this criterion of radiochemical purity is established if the experimental specific activity values of a compound in successive areas are constant within limits of experimental error.

In Figs. 5 and 6, each specific activity value is plotted on an ordinate scale against distance from the first measured point along the abscissa. The great effect of a contaminant on the apparent specific activity is shown in Fig. 5. In Fig. 6 the values define straight horizontal lines, with deviation of individual points not exceeding limits of experimental error. Though radioactivity levels of compounds in the latter chromatogram were very low and separation was incomplete, the ordinate values of the horizontal lines are readily recognized as specific activity values of pure compounds. They may be compared quantitatively with each other and with values similarly determined on any compound labeled with the same nuclide. In agreement with findings of earlier workers (10), the specific activity of nucleotide "a" and "b" isomers is always the same.

Discussion

Four types of contamination have been observed by routine application of the beta-photon counter to radio-

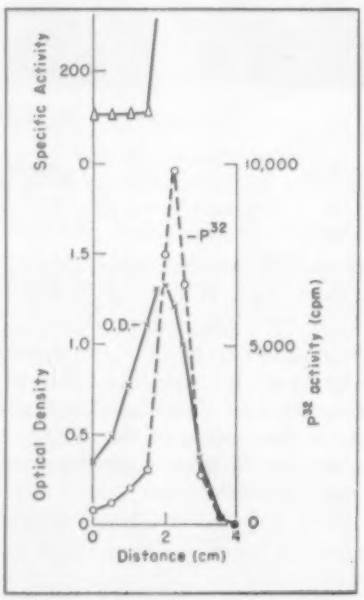

FIG. 5. Radiochemical contamination of ultraviolet-absorbing compound by non-absorbing impurity

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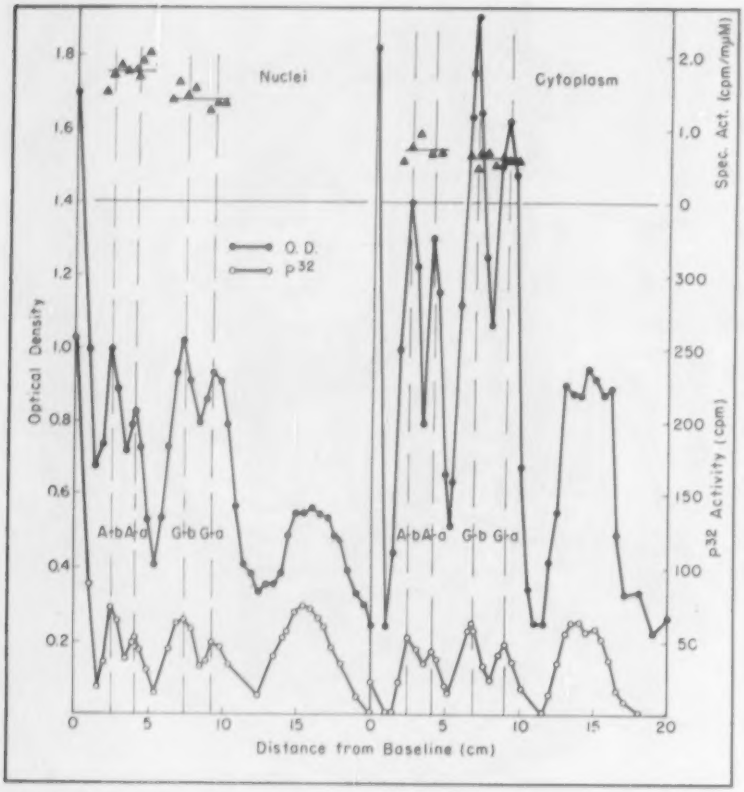

FIG. 6. Radioactivity, optical density and specific activity of compounds deposited at identical areas of papergram; isomeric adenylic and guanylic acids from nuclei and cytoplasm developed in two lanes of same paper

active light-absorbing compounds in papergrams developed by chromatography and electrophoresis:

1. Radioactive, nonabsorbing contaminant that travels ahead of compound leaving trail of radioactivity along lane of transit.

2. Radioactive, nonabsorbing contaminant with compact distribution overlapping but not coinciding with compound (Fig. 5).

3. Radioactive, absorbing contaminant with activity/density ratio different from that of the expected compound.

4. Nonradioactive absorbing contaminant.

These arbitrary categories of contamination were found on application of chemical separation procedures conventionally used in preparing pure ribonucleotides from polymerized ribonucleic acid. While a healthy skepticism of specific activity values cited without criterion of radiochemical purity is nothing new among responsible investigators of nucleic acid metabolism (*11–13*), it appears that the semiquantitative criteria described previously will often fail in detection of radiochemical contamination. Thus, the method whereby ultraviolet photographs are compared visually with radioautographs (*11, 12*) would require virtually unattainable photographic technique and subjective discernment to reveal instances of contamination encountered in this laboratory (e.g., Fig. 5) and clearly delineated with the beta-photon counter.

This methodology for determining specific activity has been applied for nearly two years. It is the method of choice even in conjunction with separations where contamination has never been observed. Thereby a safeguard against error due to external contamination is provided for each specific activity determination. Except for compounds of very weak radioactivity, the method is faster than other procedures.

* * *

This work was supported by the U. S. Atomic Energy Commission under contract AT-(30-1)-1119. Photographs are by Edward R. Hajjar and Milton Kurtz, Department of Photography, Francis Delafield Hospital.

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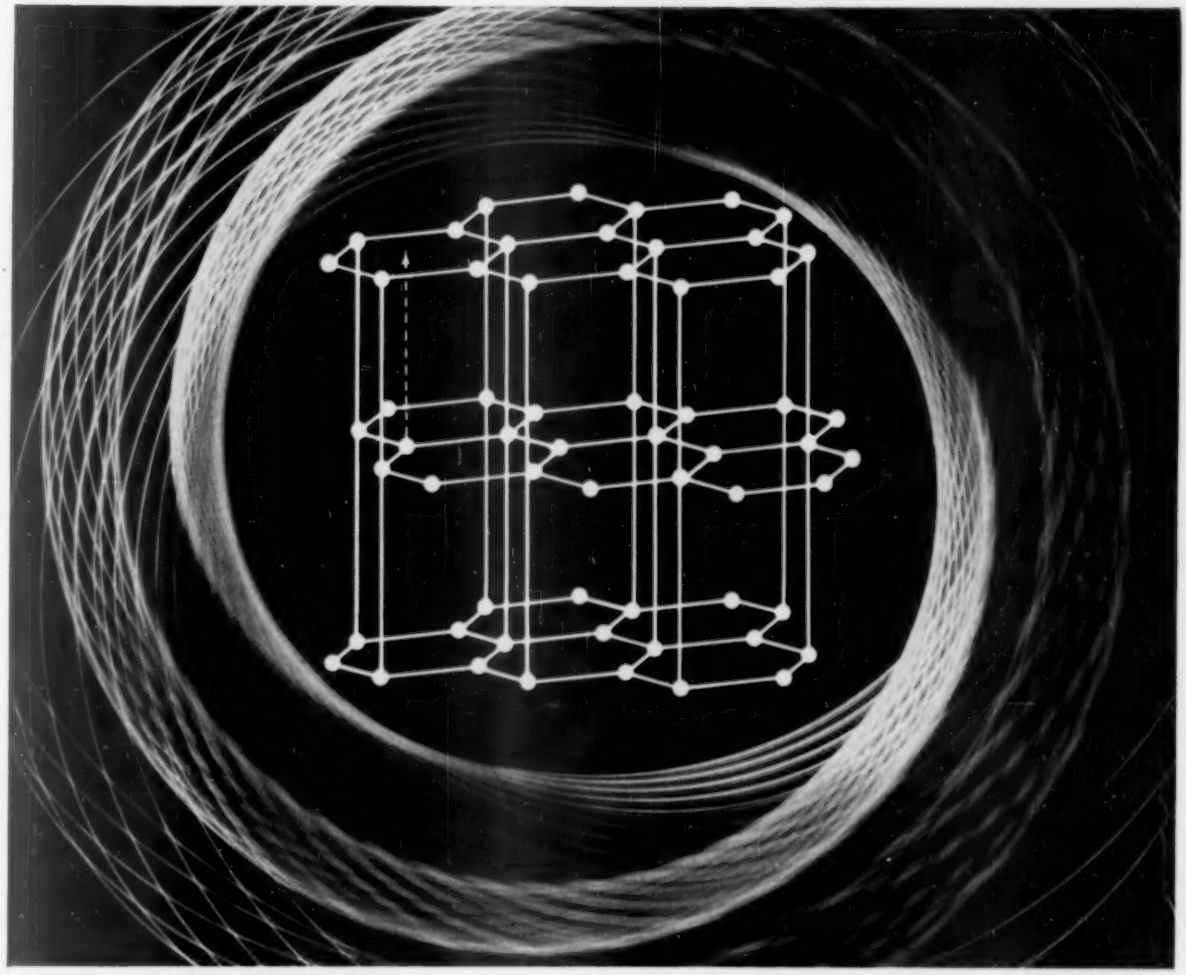
Semiconductor Fast-Neutron Dosimeter

By BENEDICT CASSEN, THOMAS CROUGH, and HERBERT GASS
Atomic Energy Project
School of Medicine
University of California
West Los Angeles, California

Lark-Horowitz* and collaborators have shown that the electrical conductivity of certain semiconductors, notably single crystals of germanium, is appreciably modified by fast-neutron bombardment and only slightly modified by intense gamma radiation (lattice dislocations can only occur appreciably by germanium-atom recoil from photoelectron ejection; the recoil energy is small compared with the photoelectrically absorbed energy). Our study was undertaken to determine whether or not the effect in germanium single crystals could be used for measuring certain properties of a fast-neutron flux, especially in a mixed neutron-gamma field.

The practical limits of sensitivity, initially unknown, depend, among other factors, on the precision and reproducibility of resistance measurements, the initial purity, and the optimum bath temperature and its re-

* "Nucleon Irradiated Semi-Conductors," Purdue University Special Report, Reading Conference, July 10, 1950.



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producibility during resistance measurements.

First attempts showed that a fission spectrum having a fast-neutron sulfur flux of the order of 2×10^{11} and higher would produce measurable effects. However, the spread of conductivity change in a group of crystals with the same exposure was, at that time, uncomfortably large. A large proportion of the crystals showed rectification effects when the polarity was changed in d-c resistance measurements. Later, a new germanium ingot, with improved methods of preparation and measurement, showed no measurable rectification effects.

The copper leads are fastened to the crystals with soft solder. At first, these crystals were plunged directly into a suitable cold bath for measurement. Slower cooling was necessary to eliminate erratic behavior due to cracks in the crystal caused by thermal shock.

Germanium-Strip Preparation

A germanium ingot, purified by zone melting and crystallized in a thermal gradient as a single crystal, is sliced into 0.030-in.-thick slabs. The slabs are cemented to a backing and cut with a thin abrasive wheel into strips 0.080 in. wide and 0.160 in. long. After removing the cement, they are washed and ready to have leads soldered to them. Machining burrs are removed with 400–600 grit sandpaper.

After micrometer measurements, the crystal ends are lightly touched to a blotter containing zinc chloride flux and then drawn across a pool of hot 50/50 solder in such a way as to leave a smooth investure of solder adhering to the whole end surface.

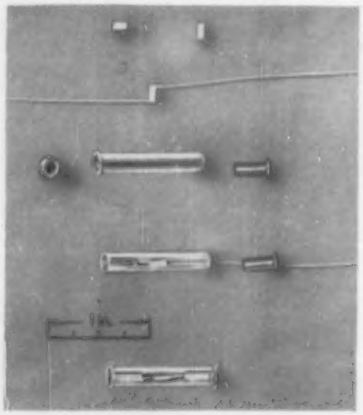
Individual strands of 6-mil-diameter copper wire are then tinned and quickly fused into these solder investures. The junction tenacity should permit a light tug on the opposing wire junctions; rejects are put aside for reprocessing.

After washing off excess zinc chloride, the crystals with their leads are encapsulated (see illustration).

Resistance Measurement

To provide a low-temperature bath free from both viscosity changes and conductivity, Dow Corning silicone fluid No. 200 (one centistoke) was cooled by pouring it over pulverized dry ice into a 1,200-ml Dewar flask. A stirring motor maintained a temperature of about −78° C; variations were recorded by means of a copper-constantan thermocouple read on a Leeds-Northrop precision potentiometer. The thermocouple junction was encapsulated to approximate the immediate crystal environment, and the reference junction was immersed in an icewater bath.

By means of a Lucite holder, the encapsulated crystals were contacted on one end by a common plate and held by a spring contact on each opposite pole. A wire from the common pole and wires from each opposite pole were passed through a selector switch to a null-indicating d-c Wheatstone bridge arrangement by which the resistance measurements were made. The encapsulated thermocouple junction was also enclosed in the holder, and its leads passed to the reference junction and the potentiometer.



CAPSULE ASSEMBLY. Germanium crystal with leads is inserted in capsule consisting of 1-in.-long, 0.110-in.-i.d. Kel-F tube in which are pressed hollow rivets ¼ in. long with 0.115-in. o.d. Solder seals capsule and contacts leads extending through rivets

Measurements were made only when the thermocouple indicated bath-temperature equilibrium had been established. Simultaneous thermocouple and crystal-resistance readings constituted a single recording. Each crystal was read a minimum of two times at usually slightly different temperatures, both prior to and following irradiation.

Unirradiated cold resistances were 2,000–4,000 ohms. Reproducibility was 2 or 3 ohms for some batches; other batches show long-time drifts that are not yet fully understood. At room temperature, resistivity is about 40 ohm cm; at our low measuring temperature, the temperature coefficient of resistivity is positive and has a relatively low value.

Preliminary Results

First attempts to calibrate germanium dosimeters were made on the Crocker Laboratory cyclotron. This cyclotron gives off, from an external beryllium target, a fast-neutron spectrum with a maximum of about 20 Mev and a mode of about 15 Mev—much higher than fission-spectrum values. The Naval Radiological Defense Laboratory had determined a sulfur flux calibration and had calculated the first-collision rep dose as 1 rep per 2×10^8 sulfur flux. Average values of several dosimeters at each distance fit in well with the inverse-square law, although these measurements were made before the cause of previously mentioned large erratic variations was determined. The averages showed no severe deviation from linear response to as high as 37,400 rep.

After dosimeters were made that seemed to reproduce their resistance measurements much better than previously, a calibration was attempted on the Oak Ridge National Laboratory cyclotron. This cyclotron emitted, from an internal target, a fast-neutron spectrum resembling a fission spectrum. The results were very much better than any previously obtained. Averages of six dosimeters for each dose could be fit closely with a straight line from about 200 rep to 4,800 rep, intersecting the abscissa at about 125 rep.

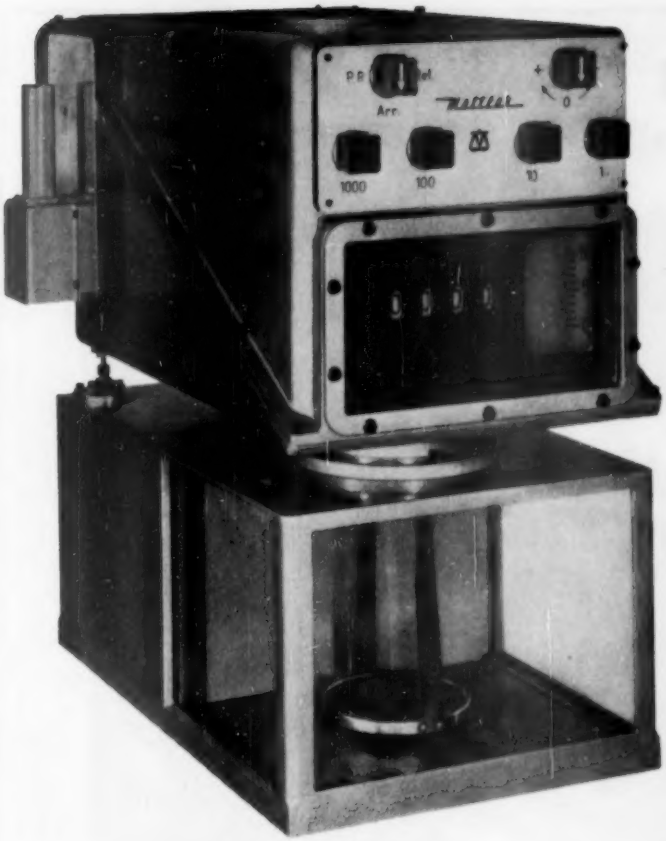
The probable explanation is that the germanium shows slight *n*-type conductivity to begin with, about 125 rep produce enough lattice defects to trap these electrons. Trapping of more electrons then leads to *p*-type conductivity, which appears to follow a fairly linear response. Dosimeters are now being preexposed to about 125 rep to see whether a linear response can be obtained below 200 rep.

There would undoubtedly be marked hysteresis effects in going through a complete cycle. However, with our procedures, the crystal remembers its fast-neutron exposure indefinitely and is normally not reused, although some work is under way to reclaim crystals by annealing them at 450° C.

Much more work has to be done, but it now appears that biologically interesting dosages of fast neutrons can be measured with this type of dosimeter.

• • •

This work was done under U. S. Atomic Energy Commission contract No. AT-04-1-GEN-12.



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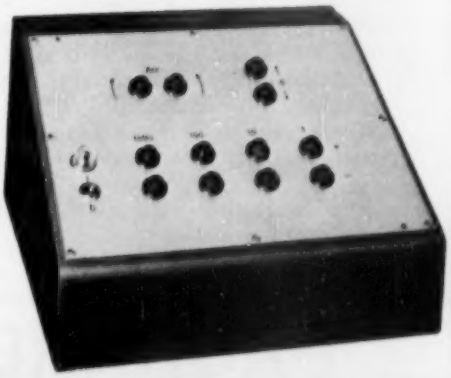

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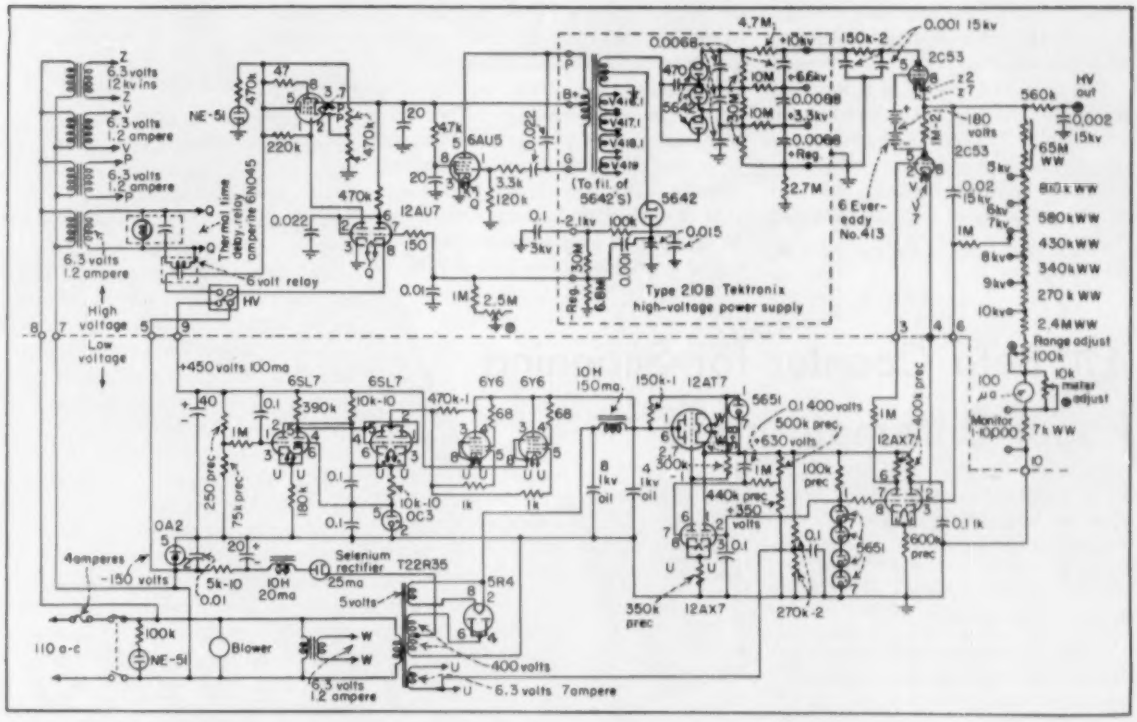

FIG. 1. Circuit diagram

Precision 5–10 kv High-Voltage Supply

By LOUIS COSTRELL
Radiation Physics Laboratory
National Bureau of Standards
Washington, D. C.

Figures 1–3 show a highly regulated positive-polarity high-voltage supply suitable for use with ionization chambers. The supply delivers up to 250 μa at 5–10 kv in steps of 1 kv. The drift over several days is about 100 parts per million and the stability over 10–15 min periods is about 10 ppm for line voltages of 100–130 volts. Except for the drop in the 560k protective resistor (which can be shorted out where desired), the change of voltage from no load to full load is less than 100 ppm. Ripple is about 30 mv, r.m.s.

The supply consists essentially of a stabilized audio-frequency high-voltage supply followed by a series regulator tube that is controlled by a balanced-feedback amplifier. All voltages, except for filament supplies, are regulated. A commercial Tektronix type 210B 2-kc power supply* is used.

The oscillator circuit that is used in conjunction with the type 210B supply is essentially that used in the Tektronix type 513 oscilloscope. Though the oscillator in the Tektronix oscilloscope is supplied from a 330-volt unregulated supply, for this application a 450-volt regulated supply is used to give increased output and improved stability against line-voltage changes. Since the oscillator draws about 100 ma at this voltage, it is driven quite hard, as is the 210B supply. A blower prevents excessive temperature rise and minimizes the temperature gradient between resistors in the precision-

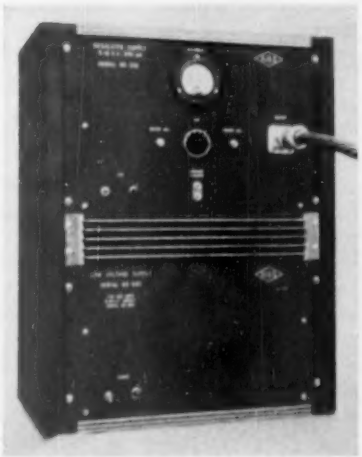

FIG. 2. 5–10 kv supply

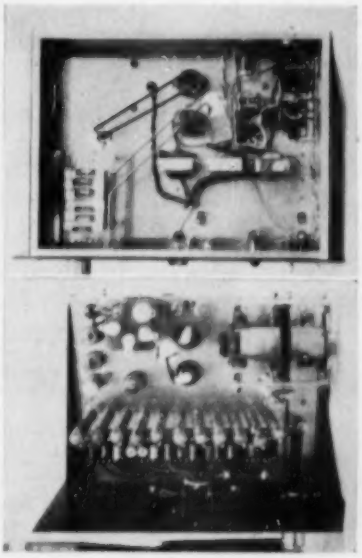

FIG. 3. High-voltage chassis (low-voltage circuits are on separate chassis)

*Manufactured by Tektronix, Inc., 713 Southeast Hawthorne Blvd., Portland 14, Oregon.

bleeder chain. The application of the B+ voltage to the oscillator is delayed by a thermal relay.

The regulator circuit is a modified version of that used in the Brookhaven 5-kv supply.* The 180-volt battery string—six Eveready No. 413 batteries—is included between the grid of the series tube and the plate of its control tube so that the current in the control tube can be sufficient to give reasonable transconductance while at the same time permitting use of a high-plate-load resistance. The battery voltage can change considerably with negligible effect on the output voltage. This is confirmed by the fact that dropping the battery voltage by 20% produced a change in output voltage of considerably less than 0.01%.

* W. A. Higinbotham, *Rev. Sci. Instr.* **22**, 429 (1951).

4π Beta Counter for Scanning Paper Chromatograms

By A. HARRISON and F. P. W. WINTERINGHAM
Department of Scientific and Industrial Research
Pest Infestation Laboratory
Slough, Bucks, England

In earlier papers considering determination of labeled compounds separated on paper chromatograms (*1*, *2*), an automatic scanning method was described (*1*) utilizing unidimensional chromatograms driven stepwise below a thin-end-window G-M tube. To avoid the losses due to the 2π geometry and window absorption, the 4π counter described here was developed.

The counter assembly (Fig. 1) consists of two hemicylindrical parallel counters, one enclosing the upper surface of a hollow platform, the other the lower surface; the whole is enclosed in a Pyrex envelope. There are no exposed edges or points within the sensitive volume of the counter. Thus, all internal surfaces, including the edges of the platform slots through which the paper is exposed, are polished. The bolts holding the platform plates to the supporting rods are countersunk. The longitudinal edges of the copper-foil cathode meet at one side of the platform. The small hairs of a paper chromatogram passing through the platform are presumably too short to reach into the sensitive volume.

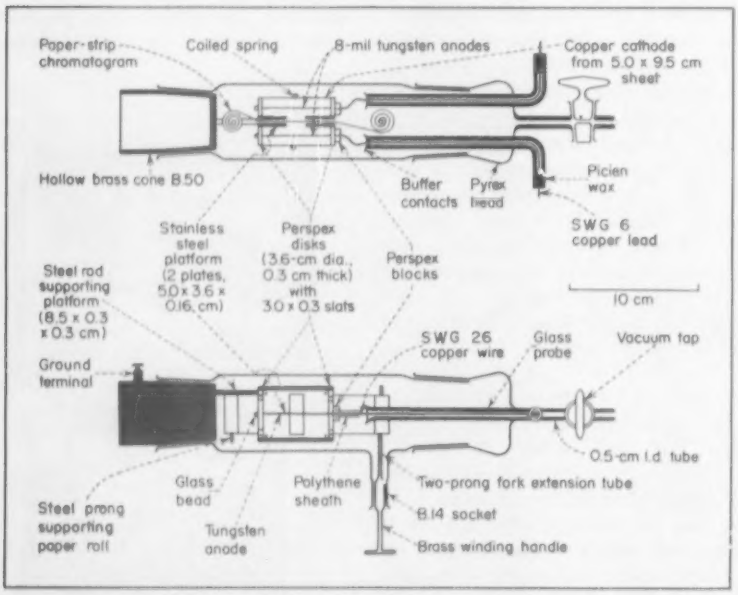

FIG. 1. Sensitive volume of G-M counter is around hollow platform supported by brass cone; copper sheet, bent around Perspex disks and held by spring, forms cylindrical cathode. Anodes are on opposite sides of platform. Winding handle, engaging free end of paper strip by pronged extension, draws paper through platform; 1-cm lengths of paper are exposed

Assembly and Gas-Filling

All parts of the apparatus are kept scrupulously clean and free of small hairs, etc. Radioactive contamination is avoided at all cost.

The paper chromatogram, which may be 50–60 cm long but not more than 3.0 cm wide, is marked off lightly in pencil in 1-cm sections and numbered. By observing through the glass envelope (when the counter is assembled) the number of the section entering or emerging from the platform, the section exposed to the sensitive volume of the counter can be identified.

The strip is rolled up tightly once or twice and the coil placed on the prong of the platform supporting rod. The free end of the paper is then fed through the platform until about 5 cm emerge. The brass cone is smeared with vacuum grease (not silicone) and inserted into the socket of the glass envelope. With the help of forceps held in the open end of the envelope, the brass winding fork is inserted so that the prongs engage the free end of the paper emerging from the platform. The Pyrex head is greased and placed on the cone of the envelope so that the small copper disks on the glass propes contact the bent copper extensions of the counter anodes.

The loaded counter, now ready for gas filling, is attached to the manifold shown in Fig. 2.

After filling, the counter is disconnected from the manifold and placed within a lead castle, which provides 3 in. of lead all round the counter. The counter platform is exactly horizontal. By removing two roof bricks of the castle, the portion of the paper strip just emerging from the platform can be viewed through the glass envelope. The paper-winding handle projects through a gap in the side of the castle.

Auxiliary Circuits

With the shielded counter in its normal position (the anodes horizontal, parallel, and in the same vertical plane), up to one-half the total background counting rate (40–50 cpm) was apparently due to cosmic rays, which gave rise to coincident pulses in the "half-counters." By means of a coincidence circuit, the background counting rate was effectively reduced to about 25 cpm. Moreover, this remaining background counting rate will be far less

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likely to be subject to the nonrandom fluctuations due to cosmic rays (*3*).

Although the circuit units to be described here are identified by the "type" numbers in use in Atomic Energy Research Establishments, the counter would presumably operate equally well with other units of similar function.

Both counters operate in the Geiger region at about 1,500 volts. Since the threshold voltages of the "half-counters" usually lie within a few volts of one another, separate high-voltage control is unnecessary. The HV for both counters is drawn from a single type 200 unit via two type 200 probe units separately operating from each counter anode.

The probe units are single-tube amplifiers with no quenching facilities. The ethanol vapor of the counter gas filling provides adequate quenching at the low counting rates for which the counter is designed. External quenching units that operate by reducing temporarily the anode voltages of the counters are unsuitable; the negative pulse (e.g., −200 volts) applied to one half-counter anode invariably induced a pulse in the other half-counter, the event being erroneously recorded as a cosmic-ray coincidence.

The output pulse of each probe unit is applied to the *Y*-plates of a double-beam cathode-ray oscilloscope on a 15-msec *X*-sweep. At background counting rates and when the juxtaposition of the two beams is properly adjusted, coincidences can easily be seen on the oscilloscope screen to check the performance of the counter, coincidence unit and scalers.

The output pulses of the two probe units (+15 volts) are fed separately into the first and second channels of a type 1036A coincidence unit. After amplitude discrimination, etc., they are fed to corresponding first and sec-

Counter Characteristics

Threshold voltage (both "half-counters")	1,400 volts
Plateau	200 volts
Slope—negligible over operating range	
Total effective background counting rate (excluding coincidences, 3-in. lead shielding)	25 cpm
Effective efficiency for C^{14} deposited on chromatogram paper (8.8 mg/cm²)	32%
Estimated efficiency for C^{14} betas escaping from chromatogram paper	87%
Effective efficiency for H^3 deposited on chromatogram paper (9.3 mg/cm²)	0.22%

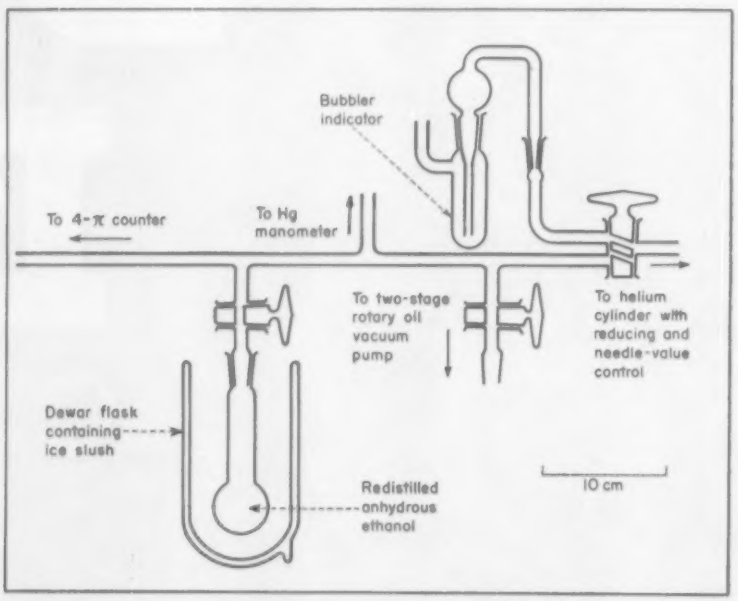
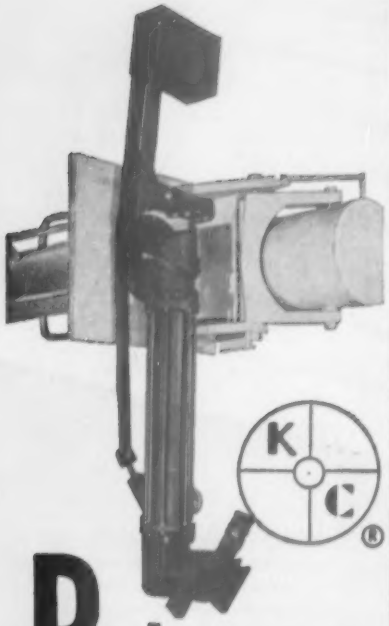

Bubbler indicator
To 4-π counter
To Hg manometer
To two-stage rotary oil vacuum pump
To helium cylinder with reducing and needle-value control
Dewar flask containing ice slush
Redistilled anhydrous ethanol
10 cm

FIG. 2. Gas-filling manifold. Air in rubber-tube connection to helium cylinder is flushed out through bubbler. Counter and manifold are then pumped out. Ethanol vapor in equilibrium with liquid at 0° C is admitted to counter and 15 min allowed for equilibration. With counter and ethanol reservoir isolated, manifold is pumped out and helium admitted to counter to within 1–2 cm of Hg short of atmospheric pressure. After 15-min equilibration, counter is disconnected



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ond type 1221B cold-cathode-Dekatron scalers.

The pulses from the first and second channels of the coincidence unit, after a variable delay, are fed into the unit's mixer channel. When two pulses arrive within the variable resolving time of the mixer channel (normally 2 μsec), a single pulse is passed on to a third 1221B scaler type. The incidence of spurious coincidences within this time was negligible at counting rates below 2,000 cpm.

All three scalers are controlled by a single type 1221B preset timer. Thus, the three scalers record the total counts of the upper half-counter, the lower half-counter, and the coincidence counts.

Performance

During six months of regular use for scanning C^{14}-labeled compounds separated on paper chromatograms, the electrical characteristics of the counter (see table) have remained apparently unchanged.

The efficiency for C^{14} was estimated by spotting a labeled compound on Whatman No. 1 paper and comparing the counting rates obtained in the 4π counter and when mounted below a thin-end-window (2 mg/cm²) G-M tube calibrated with a C^{14} standard. The efficiency of the end-window tube was 4%. The 4π counter was thus 8 times as efficient as the end-window counter. The efficiency for the C^{14} betas escaping from the paper (87%) was estimated on the basis that 63.4% of the betas would be lost by self-absorption in 8.8-mg/cm² paper (*1*).

The efficiency for H^3 (labeled hydrocortisone acetate) was estimated by comparing the counting rates obtained with the 4π counter and with a gas-counting technique having a calibrated efficiency of 50% (*4*).

Although designed for scanning soft-beta emitters separated on paper, the 4π counter has been very useful for comparing the C^{14} content of small liquid samples deposited by evaporation at suitable intervals along a filter paper strip. When a series of ten samples of C^{14}-labeled allethrin was assayed in this way, the over-all coefficient of variation was ±4.2%. This included the variation due to 10-μl pipetting, to self-absorption variation due to the paper (*1*), and to the statistical variations of random counting, the last being calculated in the usual way to be ±2.1%.

A further application of the 4π coun-

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TECHNICAL DATA The basic properties of the cathode ray tube that concern the designer or the user are: deflection sensitivity, unit line brightness, line width, static voltage requirements and physical size. A comparison between cathode ray tubes manufactured by Waterman Products Company is shown in the table below. These tubes are available in P1, P2, P7 and P11 phosphors. 3JP1, 3JP7, 3SP1 and 3XP1 are available as JAN tubes.

TUBE	PHYSICAL DATA			STATIC VOLTAGE			DEFLECTION*		LIGHT OUTPUT**
	Face	Length	Base	A3	A2	A2 Max.	Vert	Hor	
3JP1	3"	10"	Med Diheptal	3000	1500	2000	111	150	352
3MP1	3"	8"	Sm Duodecal		750	2500	99	104	33
3RP1	3"	9⅛"	Sm Duodecal		1000	2750	61	86	44
3SP1	1.5x3"	9⅛"	Sm Duodecal		1000	2750	61	86	44
3XP1	1.5x3"	8⅞"	Loctal		2000	2750	33	80	218

*Deflection in volts per inch.
**Light output of an element of a raster line (one mm long and not exceeding .65mm in width) in microlumens.

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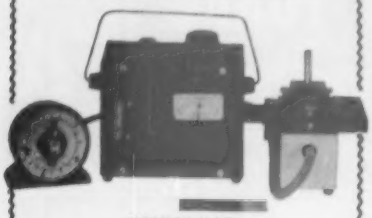

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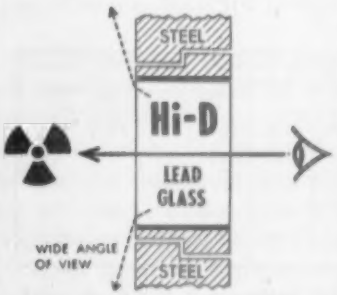

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ter has been to the simultaneous determination of a mixture of Cl^{36}- and C^{14}-labeled compounds separated on a paper chromatogram. A 28-mg/cm² mica screen fitting exactly into the slot of the upper platform effectively screened off all the C^{14} betas while passing approximately 60% of the Cl^{36} betas. Thus the top half-counter was sensitive to 0.6 × Cl^{36} activity only and the bottom to the total Cl^{36} + C^{14} activity, which enables the isotopic composition to be deduced.

* * *

The authors are indebted to Mr. M. A. Cordaroy for the construction of the platform assembly in the instrument shop of this laboratory, and to Dr. J. F. Tait of the Barnato Joel Laboratories, London, for samples of H^3-labeled hydrocortisone acetate separated on a paper chromatogram. This paper is published by permission of the Department of Scientific and Industrial Research.

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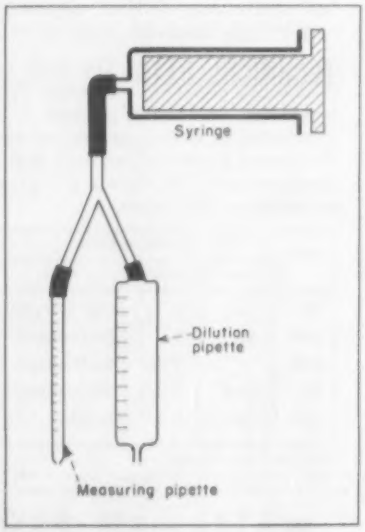
Simple Micropipette



By IRVING FEUER
Polytechnical Consultants
New York, New York

An inexpensive micropipette* can be constructed from common laboratory components, i.e., a syringe, a measuring pipette, and one or more pipettes operating in parallel.

* Patent pending.

The sensitivity of the measuring pipette can be expressed as (volume displaced in measuring pipette)/(plunger displacement in syringe). With the dilution pipette, one obtains greater linear displacement of the plunger for a fixed volume in the measuring pipette, thereby increasing the operator's control (see illustration).

This technique can be extended to multiple pipettes. Thus, for measuring radioactive liquids, one pipette takes up the liquid, a second is the dilution pipette, and the third (the same volume as the first) takes up a nonradioactive liquid to indicate the volume of radioactive liquid.

TECHNICAL BRIEFS

• **Iodine-132** radiation measurements were reported by N. Veall (*Nature*, Nov. 6, 1954, p. 889), useful in biological tracer studies. The dose rate from 1 mc I^{132}, by ionization measurements, was 12.1 r/hr at 1 cm; the mean β-ray energy per disintegration was 0.45 Mev. The half-life was determined to be 2.259 ± 0.003 hr.

• **Cancer of the pancreas** can be given a localized dose of up to 9,000 r by a technique developed by Paul Harper, University of Chicago Dept. of Surgery. Polyethylene tubing, filled with I^{131} solution and air or mercury and sealed at the ends, is threaded around and through the tumor. At the end of treatment, the tube can be withdrawn or left in the patient.

• **A semiconductor-diode amplifier,** based on carrier-storage effects, with a gain of 10 for <1-μsec pulses has been developed by A. W. Holt of NBS. Principal application thus far is to computer-like regular pulses. If the voltage across a diode is suddenly switched from forward to reverse, the high reverse resistance characteristic of the steady state is not achieved immediately. Rather, the carriers that were responsible for the forward current are swept out by the reverse voltage, giving an appreciable reverse current for a time T of the order of 1 μsec for germanium point-contact diodes, less for silicon.

A square wave of frequency $\cong 1/T$ alternately applies 0 volts or 20 volts reverse voltage to the diode. Pulses to be amplified are applied in the forward direction during the time that the square wave is at zero. The next reverse-voltage excursion of the square

wave sweeps the residual carriers out, giving an output pulse of similar current but higher voltage than the input. There is a significant resemblance to transistor action here: carriers are injected at low impedance and are taken out at high impedance, but instead of these being emitter and collector, they are the same junction, the square-wave biasing voltage having changed its character.

• **Two standard source wells** have been constructed at the Naval Research Laboratory for calibrating radiation detectors and measuring radiation effects on materials. Cobalt-60 sources (50 mc and 7 c) have been used to give calibrated field values of 0.002–100.0 r/hr to within 3%, reproducible to within 0.3%; Cs^{137} (50 mc) was used for 0.001–0.45 r/hr to within 5%, reproducible to within 0.3%. Both wells consist of 12-in. o.d. steel tubes driven 18 ft into the earth, a 2-in. outer layer of lead surrounding 4 ft of the upper end of the high-intensity well and 6 ft of the low-intensity well. A 10-in.-diameter tube, telescoped into the larger tube, contains a track upon which the source carrier is positioned by a metal-impregnated flexible tape.

High-intensity wells are being designed for 100–130 curie Co^{60} and 100 curie Cs^{137} sources to provide fields of 1,000 and 500 r/hr, respectively.

• **Radiation effect on paint.** After exposure to 1.25-Mev γ's from Co^{60} for 3.5×10^8 r, vinyl-base Corrosite, Nukemite, and Amercoat-23, -33, and -55 on Al panels had surface blisters and large amounts of halide. Film failure was due to hydrogen halide attacking Al. Amercoat-23 and -55 on steel panels failed similarly after 5×10^8 r.

No failure was evident in Corrosite, Nukemite, GE Cocoon, Amercoat-23, -33 and -55, Zerok-110, Alkaloy-550, Amphesive-801, Prufcoat, Duralon-36, and Ampreg on concrete after 10^8 r. After 7.4×10^8 r, microscopic examination revealed small colored surface spots on Amercoat-33 and -55, GE Cocoon, Corrosite, and Nukemite.

Kel-F failed after 10^7 r. Black Amerplate, white-polyethylene Amerplate, and flame-sprayed polyethylene failed after 10^8 r. Doses of 10^9 r caused failure of sheet strip coats of Black Brevon, Blue Tygofilm, Black A89A, GE Cocoon, and Amercoat strip.

Tests were conducted at Oak Ridge National Laboratory and the National Reactor Testing Station.

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Using a

Scintillation Spectrometer for Determining Uranium Burnup

By J. H. KITTEL
Metallurgy Division
Argonne National Laboratory
Lemont, Illinois

The determination of atom burnup in irradiated fuel material can be subject to large errors when activated monitors are used. When irradiation conditions are such that errors will be present if monitors are used, burnup is best determined by measurements made on the fuel specimen itself. The method that is described here uses a simple chemical separation and a scintillation spectrometer to determine total fissions in a fuel specimen.

Using a Monitor

The exposure of neutron-irradiated fissionable material is commonly reported in terms of "burnup," or the fraction of total atoms in the material that has undergone fission. If the material is irradiated in a pure thermal-neutron flux along with a suitable monitor material, then the burnup readily can be calculated from the flux determined from the monitor activity, assuming, of course, that the necessary cross sections are known accurately.

Experimental reactor irradiations of fuel materials, particularly when at high neutron fluxes, often are made under conditions where an appreciable number of fast and resonance neutrons are present, and thus large errors can develop if the experimenter uses an activated monitor as a means of calculating burnup in his fuel specimens. If, for example, natural uranium is being irradiated under these conditions and cobalt is used as a monitor, the following processes will occur at unknown rates: (a) the cobalt will acquire excess activity because of its relatively high resonance activation cross section at 120 ev; (b) U^{238} will be fissioned by fast neutrons; (c) U^{238} also will be converted, mainly by resonance neutrons, into Pu^{239}, an appreciable fraction of which may then undergo fission by thermal neutrons.

In addition, errors may arise even in a well-thermalized location because of an unknown flux gradient between the monitor and the fuel specimen, and because of self-shielding within the specimen. Under such conditions, burnup is best determined by measurements made on the fuel specimen itself.

Measurements on the Fuel

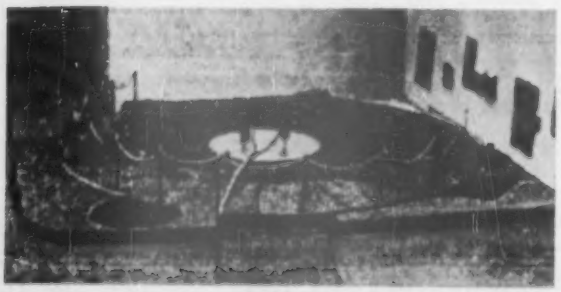
The most reliable determination consists of measuring the amount of a fission product having a known yield. Thus, the total number of atoms fissioned can be determined, and if the total atoms in the sample are known, the burnup is calculated readily. One of the most satisfactory fission-product isotopes for this purpose is Cs^{137}. It has the advantages of high, almost equal yields in the fission of U^{233}, U^{235}, and Pu^{239}, and it has a suitably long half-life (33 yr).

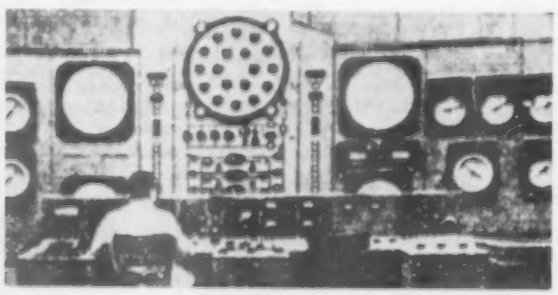
Cesium activity usually is separated from other fission-product activity by precipitation in ethanol as the perchlorate (*1*). Then it is mounted and beta-counted under standardized conditions. This procedure, while yielding high precision, suffers from an inherent disadvantage in that 2 or 3 months' decay is required to eliminate the beta contribution from 12-day Cs^{136}.

On many occasions, particularly for preliminary values, a less precise but simpler determination would suffice. Gamma-counting with a high-resolution scintillation spectrometer has been shown to be an attractive method of furnishing a quick qualitative analysis of fission products (*2*). A method will now be described by which the instrument can also be used for quantitatively determining the number of fissions in a given sample.

The circuit used for counting consists of a single-channel pulse-height analyzer and a negative high-voltage unit, both designed and built under the direction of T. Brill of the electronics division of Argonne National Laboratory. The scintillation unit consists of a high-resolution sodium-iodide probe designed and built by R. Swank of Argonne's instrument research division (*3*). The probe is used in an iron shield. Counting samples are prepared from uranyl nitrate solutions containing known uranium concentrations.

If the gamma spectrum of a natural, unseparated mixture of fission products is surveyed, it will be found that





TOP OF RUSSIA'S 5-Mw reactor (left) (NU, Aug. '54, p. 60) and console (right) are shown in recent photos in Pravda, Russia's Communist-party newspaper. A 100-Mw reactor power is planned

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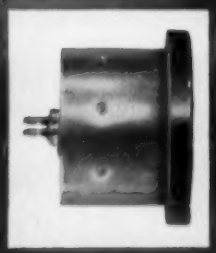

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the only activities that interfere with the 0.663-Mev gamma of Cs^{137} are the 0.708-Mev gamma of Zr^{95} and the 0.758-Mev gamma of Nb^{95}. These can be removed readily from the sample by $Fe(OH)_3$, after which the Cs activity is counted as the chloroplatinate. The chemical procedure, which takes less than ½ hr for four counting samples, is as follows: (a) to 4 ml H_2O in 40-ml centrifuge tube add aliquot of active solution containing a known concentration of uranium and 1.00 ml Cs carrier solution (standardized by $CsClO_4$ procedure) (*1*); (b) heat to boiling, then add 5 drops 10% $Fe(NO_3)_3$; (c) add about 2 drops 6*N* NaOH dropwise to form $Fe(OH)_3$ and centrifuge, pour supernatant into clean tube; (d) repeat (a) and (b); (e) add 10 drops 5% H_2PtCl_6, agitate, allow to stand one or two minutes, and then wash with ethanol onto weighed filter disk (Whatman No. 50); and (f) dry in vacuum desiccator, weigh, mount, and gamma-count as Cs^{137}.

The sample is counted so as to determine the valley depth near 0.54 Mev, the maximum peak height near 0.66 Mev, and the valley depth near 0.74 Mev. If the Zr and Nb have been properly removed, the peak-to-valley ratio will be about ten. With the same geometry, an identically mounted sample containing a known number of fissions is counted, and if the integrated counting rate is low enough to avoid resolution losses (<50,000 cpm), it will be found that a direct proportion exists between peak heights and number of fissions in the counting samples, from which fissions in the unknown can be calculated. If the number of uranium atoms in the aliquot is known, the fraction that has fissioned can be readily determined.

* * *

The author acknowledges the help of E. Turk of Argonne's chemical engineering division, who standardized the Cs carrier solution and determined the fissions in the solution from which counting standards were made, and R. Milham of the same division, who provided suggestions on separation procedures and instruction on use of the counting equipment.

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2. C. E. Crouthamel, C. E. Johnson, ANL-4924 (1952)
3. R. Swank, J. S. Moenich, *Rev. Sci. Instr.*, **23**, 503 (1952)

NUCLEAR POWER

Prime U. S. areas for nuclear power. In one of his last statements as an AEC

official, L. R. Hafstad said New England's high industrialization and high-cost fuel make it a "natural" for early competitive nuclear power. Other areas of the U. S. with high-cost conventional fuel are: (a) Nevada, Oregon, and adjoining portions of California and Idaho; (b) most of South Dakota with nearby Minnesota, North Dakota, and Kansas; (c) northern Michigan and Wisconsin; and (d) most of Florida and part of southern Georgia.

W. Germany studies reactor graphite. Graphite of density considerably over 2.0 gm/cm³ is being counted on to make possible use of only 25 tons of natural uranium in West Germany's proposed 10-Mw reactor (NU, Feb. '55, p. 75).

Experiments on low-boron powdered graphite with a crystal density of 2.4 have indicated a diffusion length of 45 cm, but confidence exists that further purification will give a graphite whose diffusion length will be 48 cm for a density of 1.6-gm/cm³.

First of the group's sigma pile diffusion-length studies involved slabs of 1.6-gm/cm³ graphite as used in the electrical industry. An 8.2-ft cube of graphite with a 500-mc Ra-Be source centered on the bottom surface was used in the conventional manner. Later, a method originated by Karl Wirtz was employed. The new technique, said to be faster and more accurate, used the same source centered in a 23.6-in. graphite cube surrounded by 11.8 in. of paraffin. Both methods involved indium foils as detectors and yielded diffusion length of 43 cm.

Belgians use exponential pile to find properties of British-supplied graphite. Belgium's exponential pile, 1,410 ft³ and 14¾ ft high, has been used to find that the graphite supplied by Great Britain (NU, Aug. '54, p. 56) has a 48.1-cm diffusion length. The exponential pile uses 68 tons of graphite and 3,000 Al-clad U slugs weighing a total of 6 tons. Lattice spacing is 18 cm; $(\text{buckling})^2$ is 1.33×10^{-4} cm^2. Four 2-c Ra-Be sources were spaced equally at the bottom of the stack. The graphite will be stacked in a 22-ft cube in Belgium's reactor, which also will have two graphite thermal columns.

Maximum burnup. For a given fuel element, maximum burnup can be achieved by shifting the element to several flux-density positions during its time in a reactor.

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TECHNICAL ADVANCES

Highlights of Physicists' Meeting

Here are some highlights of the recent New York meeting of the American Physical Society. The emphasis is entirely on instrumental techniques.

Fixed-field accelerators. Betatrons with $10^4\times$ more current, synchrotrons with stable orbits for particles from 0.5 Mev to 20 Bev yet using d-c magnets . . . these may result from a new design principle for circular accelerators. The secret lies in magnetic-field configurations even more complicated than those used in strong-focusing machines currently under design. Almost any desired radial dependence of energy can be achieved. Since the magnetic field is not pulsed, tracking will not be required of synchrotron r-f systems and high repetition rates will substantially increase intensities. For betatrons the higher currents arise from the fact that electrons can be injected over a larger fraction of the machine cycle. Implementation will come slowly for Bev machines, but application to low-energy betatrons may come soon. Tough pole-piece-design and stability studies are being followed by Midwestern Universities Research Association group under D. W. Kerst.

Bilateral development. Thick photographic emulsions used in nuclear research must be developed very slowly to insure uniformity. Fox and Waniek (Harvard U.) speed this up by developing from both sides of a stripped emulsion. The pellicles are cemented between gauze pads fixed in a frame. Processing solutions can pass, expansion in thickness is possible, but track-distorting longitudinal motions are prevented.

Autoradiography intensified. K. H. Sun (Westinghouse Research Labs) reported the use of a 10-μ layer of ZnS(Ag) to reduce alpha-particle autoradiography exposures by a factor of 100.

Frequency standard. Microwave radiation from a beam of excited ammonia molecules resonates a cavity to provide a new atomic frequency standard accurate to 1 part in 10^{11}. What's new here is that the molecules are the direct source, rather than a standard for comparison as in earlier "atomic clocks." Scheme is work of Charles H. Townes and others at Columbia U.

CERN progress report. Preliminary construction of the 197-in. 600-Mev synchrocyclotron at the European nuclear research center is underway. Magnet has been ordered, model of vibrating reed for f-m has been tested. Forecast is operation in late 1957. Strong-focusing 25-Bev proton synchrotron is still in design stage. It should operate in 1961.

Slow-neutron detector. Buttons of ZnS mixed with B^{10}-enriched B_2O_3 have been used to detect neutrons by scintillations from alpha particles produced in the $B^{10}(n,\alpha)$ reaction. Brookhaven's fast chopper uses these detectors because small size and fast rise decrease time uncertainty in time-of-flight experiments. Present design is optimized for epithermal neutrons used there, but principle should be equally useful with thermal neutrons.

How High the Vacuum

Pressures down to 10^{-10} mm are now accessible for research and experimentation. Techniques involved are baked-out glass vacuum systems, oil diffusion pumps to reach the 10^{-7}-mm region, simple all-metal valves to seal off the system, and ion-gage pumping to reach pressures below 10^{-10} mm.

A few years back it was recognized that the limitation of ion-gage readings at 10^{-8} mm was caused by effects in the gage and not by limitations in pumping techniques. A new design evolved, the Bayard-Alpert ionization gage. Its much smaller ion collector had less spurious current from secondary electrons caused by soft X-rays (from the plate) striking it. Hence the gage could measure pressures as low as 5×10^{-11} mm. Being able to measure lower pressures spurred research in attaining them.

Another limitation has recently been eliminated: the diffusion of atmospheric helium through the glass walls of the ionization gage. Evacuating the region outside the gage, Westinghouse researchers L. J. Varnerin and D. White have now recorded pressures below 10^{-11} mm.

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BOOKS

Permissible Dose from External Sources of Ionizing Radiation (National Bureau of Standards Handbook 59)

Recommendations of the National Committee on Radiation Protection (Government Printing Office, Washington, D.C., 1954, 79 pages $.30). Reviewed by JOHN Z. BOWERS, Radiobiology Laboratory, University of Utah, College of Medicine, Salt Lake City, Utah.

In 1946, the National Committee on Radiation Protection established a Subcommittee on Permissible Dose from External Sources, under the Chairmanship of Dr. G. Failla. Since this beginning, in addition to its own meetings, the subcommittee and its consultants have held a series of meetings with fellow scientists from England and Canada (Tripartite Conferences) to consider the problem and develop a report. From time to time, various recommendations of the subcommittee have been adopted in the Atomic Energy Project and in other laboratories and hospitals in which individuals are potentially exposed to external sources of ionizing radiations.

Now the committee has released a Handbook that not only details permissible doses and rules for protection, but, as documentation for these, includes a wealth of radiobiological information. The value of the handbook is further enhanced by the lucid and concise style in which it is written. For the radiobiologist, the radiologist and the radiation physicist, this might well be termed "handbook of a number of years."

This analysis is not intended to repeat or rephrase the numerous conclusions of the handbook in regard to permissible dose and rules for protection. Any person working in the radiation field must make these an essential part of his scientific armamentarium. However, there are sections of the report that are of sufficiently broad significance to deserve some further discussion.

Organization of handbook. The material is well organized and an inclusive table of contents enhances the value of the handbook as a reference source.

Clear, yet comprehensive statements on radiological terminology occupy the first section of the handbook. The section entitled "Radiobiological Considerations" contains an excellent discussion of the essential facts concerning the biological effects of radiation. Following a section on protection criteria, the remainder of the handbook sets forth a series of rules and recommendations that cover all aspects of permissible exposure and protection from external sources of radiation.

Considerations of dose. Since a considerable portion of the handbook turns about discussions of permissible weekly dose, it should be understood that the committee means "a dose of ionizing radiation accumulated in one week (7 days) of such magnitude that in the light of present knowledge exposure at this weekly rate for an indefinite period is not expected to cause appreciable body injury to a person at any time during his lifetime."

The second section of the handbook includes an excellent discussion of the concept of "dose of radiation." The distinction between dose in roentgens and absorbed dose as energy absorption per gram of tissue is carefully made. International agreement has been reached on the unit of absorbed dose (International Commission on Radiological Units, Copenhagen, July, 1953); this unit is called the *rad* and is 100 ergs/gm. Agreement on this new unit makes the previous unit, the *rep*, obsolete and thus eliminates the different numerical values that have been used in the literature for the rep (83–93 ergs/gm). The difference between the most frequently used numerical value for the rep (93 ergs/gm) and that for the rad (100 ergs/gm) is negligible in the consideration of permissible dose, so that no changes are needed in the numerical values of permissible dose levels previously reported in rep.

Since defining the unit of absorbed dose does not make it any easier to measure the quantity itself, the radiation scientist is left with the same limitations in instrumentation as before. The cavity ion chamber, with which one measures in roentgen units the ionization produced in air under special conditions by X- or gamma radiation, is the most widely used instrument.

There is no need to emphasize the intricacies of this subject, which have been considered in detail in other reports. It is fortunate that the handbook has gathered together the basic ideas relating to the problem.

Radiobiological vagaries. Happily, we know a great deal about the effects of ionizing radiations on biological systems; unhappily, we know very little about the mechanism of these effects, a point that is well emphasized in the handbook. The diverse factors that affect the response of the organism to ionizing radiations emphasize the complexity of the problem. The extrapolation of experimental data from animals to man can be deceptive. Perhaps, the increased use of canines and subhuman primates may bring a greater reliability to this transition, particularly in the study of chronic or delayed effects.

As our radiobiological knowledge advances and techniques for detecting effects in the integrated physiological organism become more refined, we reach an intersection where significance encounters sensitivity. The handbook appropriately emphasizes the difficulties in determining the degree of radiobiological significance to effects.

Genetic problem. The report handles this difficult problem well. The genetic effects of ionizing radiations are of keen interest not only to the scientific community, but to the layman as well. The subcommittee recognizes that as the percentage of the population *exposed* to ionizing radiation increases, genetic damage to future generations will become a more significant problem. (The tough question of course is, "How much radiation is required for one to be *exposed?*") As of 1954, somatic mutations in the individual or changes in the first generation offspring are the pertinent problems; the status of the situation in 1984 will be watched with interest.

Since the subject requires careful treatment, it will receive further consideration from the subcommittee geneticists, who, with outside help, will prepare a full report for submission to the committee.

Tissue dose. The discussion of tissue dose on pp. 32, 33 and 34 is masterful. As the subcommittee points out, it has been customary to generalize on tissue dose for X-rays with the approximation that in the case of soft tissue, "1 rad or 1 rep equals 1 r." However, the multimillion-volt X-ray machines that are in common use today do away with the reliability of this statement. With high voltage X-ray (70 million volts), the beam traverses several centimeters of tissue before the associated corpuscular emission becomes maximal, thus the tissue dose in roentgens decreases with depth while the tissue dose in rads in-

creases with depth. A somewhat similar situation applies in regard to bone and bone-marrow dose with multi-million-volt X-rays. For numerical equality between *roentgen* and *rad*, the X-rays should be in equilibrium with the associated corpuscular emission.

Relative biological effect. In the handbook, RBE for various radiations are based upon the biological effectiveness of X-rays with average specific ionization of 100 ion pairs per micron of water. Lightly filtered 200-kv X-rays are specified because most of the available human data are based upon this energy level.

Fast neutrons pose a particular problem because of their implication in the increased incidence of cataract among some of the cyclotron workers and the survivors at Hiroshima and Nagasaki.

For whole-body exposure to fast neutrons, an RBE of 10 is applied. For specific ionization levels in the range of alpha particles of radioactive substances (circa 5,000 ion pairs/micron of water), an RBE of 20 is recommended.

Basic maximum permissible dose. *1. Long-term exposure to X-rays:* The critical organs are the blood-forming organs, the skin, the gonads and the lens of the eye. The handbook recommends that weekly doses to these tissues not exceed about 300 mr (except 600 mr for skin). This leads to a weekly maximum permissible dose for whole-body exposure to X-ray of 300 mr measured in air in the region occupied by the person. Weekly means seven consecutive days. These levels are conservative and yet realistic. It should be emphasized that 300 mr/week is a maximum figure; it is advisable to keep one's exposure as much below this as feasible.

2. Long-term exposure to any types of ionizing radiation: The increasing use of a wide variety of ionizing radiations and the fact that there is no large body of human data available, except from Hiroshima and Nagasaki, makes the establishment of permissible weekly dose here more difficult. The subcommittee uses the RBE that applies to the most critical organ and effect under the conditions of whole-body exposure.

For adults under 45 years of age, the maximum permissible total weekly dose is 300 millirems for the blood-forming organs, the gonads, and the lens of the eye, and 600 millirems for the skin.

For adults over 45 years of age, the

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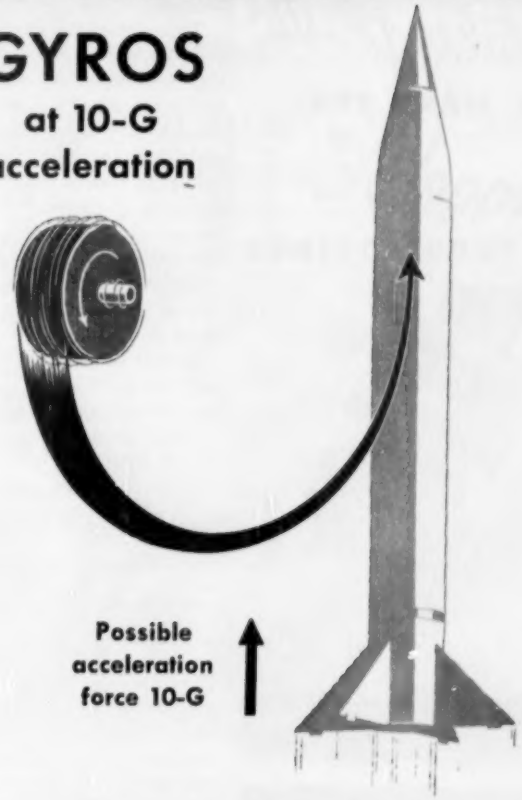

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permissible weekly dose is double these values. For minors, one-tenth of these values is allowed, except for the lens of the eye.

To facilitate the expression of tissue dose for different specific ionizations, the subcommittee recommends the continued use of the *rem*. One *rem* is the quantity of any ionizing radiation such that the energy imparted to a biological system on a gram basis by the ionizing particles in the region of interest has the same biological effectiveness as an absorbed dose of 1 rad of X-radiation with average specific ionization of 100 ion pairs per micron of water in the same region.

In this connection, there is a misprint on p. 77 under "conversion factors for radiation of high specific ionization," since dose in rem = (dose in rad) × RBE.

High-Energy Accelerators

By M. STANLEY LIVINGSTON (Interscience Publishers, Inc., New York, 1954, vii + 157 pages, $3.25). Reviewed by MILTON G. WHITE, Palmer Physical Laboratory, Princeton University, Princeton, N. J.

Professor Livingston, the author of this interesting little book on high-energy accelerators, has been in the forefront of accelerator design beginning with the first cyclotron that Professor E. O. Lawrence and he built in 1930. More recently, the author played a key role in the early design stages of the highly successful Brookhaven 3-Bev Cosmotron. Thus it is not unnatural that about one-third of the book is devoted to a description of the Cosmotron and also the powerful, alternating-gradient focusing principle of which Professor Livingston was a coinventor.

One unfortunate result of the smallness of the book is the very cursory treatment given to the whole field of linear accelerators and several other very important topics, such as aperture requirements of circular accelerators, mechanical and electrical tolerance requirements, and shielding. However, the author has succeeded admirably in packing a great deal of factual material into a few pages and the omissions merely indicate that accelerator design has now become so complex as to require a large book for adequate treatment.

The first chapter gives a very brief glimpse of the exciting new particles, the hyperons and K-mesons, which lead high-energy physicists to strive for ever higher energies and for ever higher budgets.

Chapter 2 is devoted to a simple, but clear, mathematical discussion of the orbit problem of constant-gradient circular accelerators. Chapter 3 is concerned with the electron synchrotron, while Chapter 4 describes the synchrocyclotron.

A quite different approach to high-energy particles is that of the linear accelerator. In Chapter 5 the author briefly sketches the early history of this type of device and in seventeen pages manages to touch upon a few of the difficulties and problems that designers have had to overcome.

Chapter 6, on the proton synchrotron, is very good as far as it goes, and for those who want merely to gain a general feeling for the problem this is far enough. Most of the major problems that were overcome are given sufficient mention so that the reader gains a reasonably accurate impression of the over-all balance of factors.

The last chapter gives a clear treatment of the alternating-gradient focusing principle that is revolutionizing the design of very-high-energy accelerators. Those who are at home with the constant-gradient type of focusing field may find the new principle physically somewhat unsatisfying, for not only are the equations of motion more complex but in addition the regions of instability are more ubiquitous. Particularly elusive is the momentum compaction factor that so drastically reduces the required radial aperture. More attention to this point will be welcomed by the average reader. The chapter closes with a knowledgeable discussion of some of the constructional and engineering problems yet confronting the designer. A final curve shows the energy of accelerators rising more or less exponentially from 1930 to 1954, a curve that the author wisely refrains from extrapolating. Yet it is difficult to believe that man is getting close to the energy limit dictated by economics or common prudence. Perhaps this stimulating book in the hands of engineers and graduate students will catalyze the next surge forward.

Feedback Control Systems

By GILBERT H. FETT (Prentice-Hall, Inc., New York, 1954, ix + 361 pages, $10.00). Reviewed by J. M. HARRER, Remote Control Engineering Division, Argonne National Laboratory, Lemont, Ill.

The book very ably develops the up-to-date methods of feedback-control-system analysis and synthesis. The frequency-response approach is

used and, in analyzing examples in the text, the Nyquist Criterion for system stability is stressed. Mathematical knowledge required for a grasp of the contents consists essentially of differential equations, but a background course in either complex variables or transients in which the transform theory is developed would add to the student's ability to understand the mathematical developments associated with the methods of analysis.

The text is well arranged with each important method of analysis, used currently in writing technical papers on the subject, developed in a logical sequence. The usefulness of each method is demonstrated by the use of examples, and the explanations were found to be both clear and interesting.

The author has pointed the contents at analysis of all types of systems. The first two chapters are devoted to discussing the basic ideas of control and obtaining the expressions for transfer functions of various commercial control-system components. As is fitting in feedback-control-system study, amplifiers are stressed. The transfer function of the Amplidyne, Rototrol, and Regnlix units in the rotating amplifier class are obtained as well as those for magnetic and hydraulic amplifiers.

In chapter 3, system analysis begins with the transient study of a simple servomechanism and proceeds to the steady-state analysis. Stability is covered using the Routh-Hurwitz criterion and the evaluation of roots of the polynomial resulting from the system equation. This is followed in chapter 4 with the Nyquist criterion using G and inverse-G-plane diagrams. A useful two-page summary of Nyquist loci shapes is included. This criterion of stability is then presented in the frequency plane and a second table of polar-G-plane versus frequency-plane plots for typical elements is given.

Beginning with chapter 5, the less well known methods of examining stability are discussed and examples are used to clearly establish the usefulness of each method. With the Routh criterion as a starting point, relative stability is related to the location of roots and the Root Locus method is explained. This chapter is of particular interest to those engineers already familiar with the Nyquist stability criterion and who want to go further into system analysis.

Two more chapters complete the text. Chapter 6 deals with analysis and synthesis of complex systems. It

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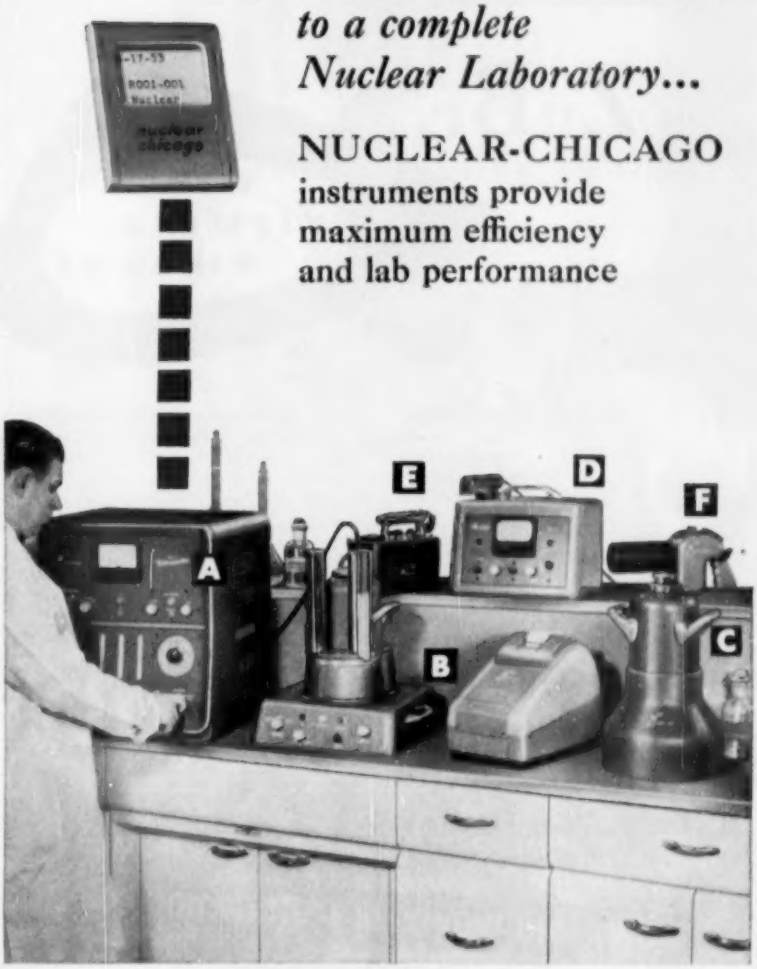

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serves to consolidate the methods of analysis developed previously in the text. The last chapter then deals with nonlinear-system analysis. This chapter is certainly worthy of study by both control engineers in the field and students who want to do advanced analytical work associated with this practical class of feedback control system. The phase plane is stressed, and variations suggested by recent papers on the subject are covered.

The book contains material of interest to all grades of control engineers. A very well set-up group of control problems is included in each chapter. The bibliography at the end of each chapter provides an excellent and concise reference list. Many of the less significant papers are omitted, making it easier for the student to obtain pertinent information without undergoing a difficult process of elimination.

BOOKS RECEIVED

Mass Spectrometry, by A. J. B. Robertson, John Wiley and Sons, Inc., New York, 1954, iv + 135 pages, $2.00. (*To be reviewed.*)

Isotopic Gas Analysis for Biochemists, by R. F. Glascock, Academic Press, New York, 1954, viii + 247 pages, $5.80. (*To be reviewed.*)

The Bomb, Survival and You, by Fred N. Severud and Anthony F. Merrill, Reinhold Publishing Corp., New York, 1954, 264 pages, $5.95. (*To be reviewed.*)

Nuclear Geology, Henry Ford, Editor, John Wiley and Sons, Inc., New York, 1954, xvii + 414 pages, $7.00. (*To be reviewed.*)

Handbook of Radiology, R. H. Morgan, Editor, Year Book Publishers, Inc., Chicago, 1955, x + 518 pages, $10.00. (*To be reviewed.*)

Industrial Automatic Controls, by Millard H. LaJoy, Prentice-Hall, Inc., New York, 1954, ix + 278 pages, $6.65. This book is an introductory text to pneumatic, hydraulic, and electronic controls and their applications. Theoretical aspects are discussed in the last two chapters.

Relativity for the Layman, by James A. Coleman, William-Frederick Press, New York, 1954, xii + 131 pages, $2.75. In nontechnical terms, the author explains the Special and General Theories, atomic and hydrogen bombs, and the Unified Field Theory.

Glass Reinforced Plastics, Philip Morgan, Editor, Philosophical Library, Inc. (Iliffe & Sons Ltd., London), New York, 1954, vii + 248 pages, $10.00. Polyesters, phenolic, epoxide, silicone, melamine, and furane resins and their use for bonding glass fibers are described, as well as manufacturing methods and applications.

Jet—the Story of a Pioneer, by Frank Whittle, Philosophical Library, Inc., New York, 1954, 320 pages, $6.00. The author describes his work in developing jet-powered aircraft.

From Classical to Modern Chemistry, by A. J. Berry, Cambridge University Press, New York, 1954, xii + 251 pages, $4.75. This book augments the author's earlier historical treatment, "Modern Chemistry—Some Sketches of Its Historical Development," with chapters on theory of heat, electricity and electrolysis, optics, molecular theory, analytical chemistry, chemical formulae, valency, and kinetic chemistry.

ALSO OF NOTE

U_3O_8—Formula for Profits. This 32-page reprint from the Sept. '54 "Engineering and Mining Journal" discusses prospecting for and mining uranium ore on the Colorado Plateau, economics and technology of ore processing, and legal problems. *"Engineering and Mining Journal," 330 W. 42nd St., New York 36, N. Y., $0.50.*

Thermal Conductivity of Metals and Alloys at Low Temperatures (NBS Circular 556). Prepared by the NBS-AEC Cryogenics Laboratory of the NBS Boulder Laboratories, this 68-page circular includes tables of thermal conductivity and 48 graphs from room temperature to about 0° K. *Government Printing Office, Washington 25, D. C., $0.50.*

Precision Laboratory Standards of Mass and Laboratory Weights (NBS Circular 547). Superceding chapters 6, 7, and 11 of Circular 3, Circular 547, by T. W. Lashof and L. B. Macurdy, presents NBS specifications for precision laboratory standards and other laboratory weights; it also discusses the regulations and weight-calibration service of the Bureau. A series of publications is planned, covering the subject matter of Circular 3. *Government Printing Office, Washington 25, D. C., $0.25.*

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LETTERS

Radiobiology Symposium

DEAR SIR:

I am writing about H. M. Patt's report of the radiobiology symposium at Liege (NU, Dec. '54, p. 42). It might interest your readers to know that the Belgian government sponsored this meeting, that I organized it, and that the proceedings of this symposium (attended by 125 people) are edited by P. Alexander and myself, published (a book of 370 pages) by Butterworth (London) and Academic Press (New York) and will be available this February.

—Z. M. BACQ
University of Liege
Liege, Belgium

Radioresistance

DEAR SIR:

I find that an error crept into our original manuscript of the article "How Processing Conditions Affect Microorganism Radioresistance" (NU, Jan. '55, p. 42) . . . The statement appears just above Eq. 1 on p. 42, where it says "from the hydroperoxyl free radical (HO_2)—a powerful *reducing* agent . . ." The statement should read "a powerful *oxidizing* agent."

Another correction could be made in the last sentence in italics on page 45 . . . The reference number should be 7 instead of 6.

—S. A. GOLDBLITH
Department of Food Technology
Massachusetts Institute of Technology
Cambridge, Massachusetts

Hazard Defined

DEAR SIR:

It has been suggested that [the following discussion of the definition of hazard] would be of interest to those engaged in the radiation-effects field. The opinions or assertations contained herein are the private ones of the author and are not to be construed as reflecting the official views of the Navy Department.

1. One of the most loosely used terms in radiation-effects work is the word "hazard." This term is used by some investigators in describing the tolerance or threshold dose for a particular type of damage from a certain type of radiation. By others it is used to represent the amount of radiation to which an individual is exposed, regardless of whether or not the radiation field will produce any significant damaging effects. According to other definitions, no hazard can exist if the radiation field is too low to produce severe effects.

2. Although this same confusion exists in other branches of study, the problem of clarity in definition is particularly serious in nuclear radiation studies, where radiations differing widely in nature and effect are nevertheless measured in common units. Thus, the biological effects of external beta radiation are only remotely related to the biological effects of external gamma radiation. Although both types of radiation produce ionization, the extent of which may be measured in rep (roentgen equivalent physical), the regions of the body affected, and the consequent result on the body, differ drastically. Gamma radiation is penetrating, produces ionization throughout the body, and thus produces direct systemic effects. Beta radiation is completely absorbed in a superficial layer of tissue whose mass is small relative to the total mass, and thus beta radiation can produce only surface burns. Consequently, the effects of the two types of radiation must be considered separately. Those who compare the relative beta and gamma "hazard," under a particular set of circumstances, strictly upon the basis of the relative beta and gamma dose are as much in error as those who compare the relative "hazards" on the basis of the respective tolerances, regardless of the magnitude of the doses to which an individual may be exposed.

3. In other words, although the beta hazard to an individual is obviously dependent upon the amount of beta radiation to which he is exposed, it is also dependent upon the extent to which he is affected by beta radiation. A similar relationship applies for gamma-radiation hazard. If, then, the critical dose, C, is defined as the threshold dose for a particular type of damage, the hazard, H, from any dose, D, may be defined as the fraction of the critical dose received. Hence, $H_\beta = D_\beta/C_\beta$ and $H_\gamma = D_\gamma/C_\gamma$ and the ratio H_β/H_γ can be used to obtain an indication of the relative importance of the beta versus the gamma radiation under any particular set of circumstances.

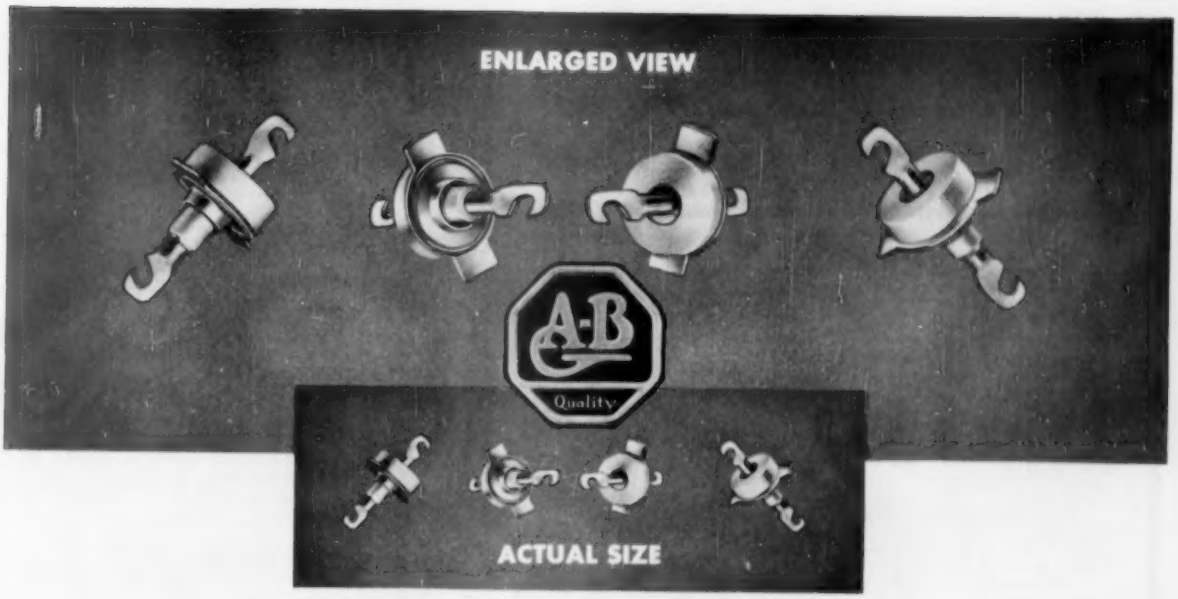
4. As may be noted, hazard is defined as a dimensionless number. If it is appreciably less than unity, the situation is not at all risky. If it is much greater than unity, the situation is dangerous indeed. Since the term is dimensionless, it may be used to compare risks from all types of unrelated sources, not only from the various types of radiation, but from radiological versus chemical or bacteriological agents. In a purely military situation, for example, a commander can numerically compare the casualties he can expect in trying to cross an open contaminated area in the face of heavy gunfire versus the casualties he can expect if he digs in and is exposed to a radiological dose for a longer period of time.

5. Before a value can be assigned for the hazard in any particular situation, it is of course important that the critical dose for the particular source of hazard be clearly established. For each source of hazard, several critical doses may be needed—e.g., for gamma radiation, critical doses include the daily maximum permissible exposure, the threshold dose for acute casualty production, the midlethal dose, etc. Since the effect of slight deviations from the critical dose is not the same for all sources of hazard, values of H in the vicinity of unity must be considered carefully. Thus, an external gamma dose 10–20% greater than the midlethal dose may produce a large increase in the number of fatalities, while an

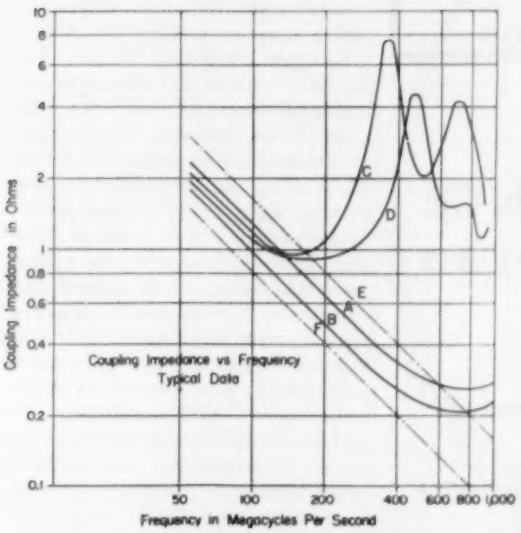
NEXT MONTH

The April issue of NUCLEONICS will include articles describing:

- **Intercomparison of neutron detectors, by H. H. Rossi et al.**
- **Graphic survey of how radiotracers are used in refinery control, by D. E. Hull.**
- **D-c amplifier designed specifically for reactor control.**
- **New application of scintillation counters to medical P^{32} assay.**
- **Pulse analysis method for determining makeup of a radionuclide mixture containing low-energy emitters.**
- **How argon treatment makes scintillators perform better.**



ANNOUNCING — An Improved UHF Discoidal Feed-thru Capacitor



Discoidal vs. Tubular Feed-thru Ceramic Capacitors

Allen-Bradley Discoidal Type	Curve A — 1300 MMF at 1 KC Actual Curve B — 1600 MMF at 1 KC Actual
Representative Tubular Type	Curve C — 1400 MMF at 1 KC Actual Curve D — 1500 MMF at 1 KC Actual
The "Ideal" Capacitor	Curve E — 1000 MMF at 1 KC Curve F — 2000 MMF at 1 KC

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Because these tiny discoidal capacitors (over-all length—23/32 in.) are so well constructed, you need not worry about breakage which might result from assembly line handling, contact with soldering irons, and thermal shock incurred in soldering operations.

In the frequency range between 100 megacycles and 1000 megacycles (VHF and UHF television), tubular type feed-thru capacitors have been found unsatisfactory because of parallel resonance effects resulting in high "coupling impedances." Allen-Bradley discoidal feed-thru capacitors do not exhibit such resonance effects at frequencies of 1000 megacycles or less.

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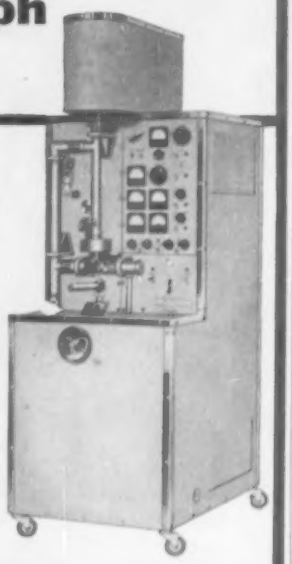

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equivalent increase in the midlethal dose for total-body external beta radiation may produce little change in the number of fatalities. Only when values of H differ appreciably from unity do they give an unequivocal insight into the true importance of any particular situation.

6. In summary, if hazard is defined as a dimensionless ratio between an expected dose and a critical dose of the same type, the term can be used to give a realistic comparison of the relative importance of various unrelated risks. It is particularly important that this be done to avoid the confusion that has arisen in nuclear radiation studies because radiations differing widely in nature and effect are measured in common units.

—A. Broido

U. S. Naval Radiological Defense Laboratory
San Francisco, California

Intensity Calculations

Dear Sir:

The article "Calculation of Radiation Intensity" by I. G. Dillon (NU, May '54, p. 19) has raised some questions that require an answer on our part.

In a previous article ("Analysis of Radiation Fields of Two Gamma-Radiation Sources," NU, Jan. '54, p. 40), Lewis, Nehemias, Harmer, and Martin have summarized certain methods of estimating dose rates in regions surrounding hollow cylindrical sources of radiation. These methods were then applied to the calibration of two particular sources. . . In general, two different approaches were used in the estimation of dose rates. The first was to consider the source to be transparent to its own radiation, and the second was to consider self-absorption by the material of which the source was made. Experimentally measured dose rates were then compared with the mathematical correlations.

These mathematical developments have been questioned by Dillon, and the authors are presenting herewith a clarification of some points of the earlier article. Dillon states, "However, the authors feel that the calculations presented here are much simpler and more accurate for wide ranges of variables than those presented by Lewis." Dillon objects to the use of elliptic integrals and states," . . . such complexity is unnecessary for radiation received at a point p along the vertical axis of the cylinder cavity."

Near sources that are assumed to be

transparent, elliptic integrals are required for the estimation of dose rates at all points not on the axis of a hollow cylindrical source. If one is interested in points on the axis of the cylinder, he may either develop another equation based on the special location of the axis, or he may observe that on the axis of the cylinder, the elliptic integrals degenerate to circular angles. Dillon is correct but redundant in stating that inverse trigonometric functions are adequate to describe the special case of dose rates on the axis. The authors were aware of the development described by Dillon, but were interested in dose rates not on the axis of their sources. Moreover, the expressions developed for dose rates in the regions surrounding hollow cylindrical sources can be shown to degenerate into simpler mathematical forms when the source of radiation is considered to be a line, or when the source becomes very long with respect to its radius and with respect to the radial distance of the receiving point. In addition, simplified expressions result when the point receiving the radiation is on the mid-plane of the cylindrical source, when the radial distance of the receiving point becomes very great with respect to the axial dimension of the source, and when the axial dimension of the receiving point becomes very great with respect to other dimensions involved. Other degenerate forms can be derived by manipulation of the elliptic integrals employed for hollow cylindrical sources, but space does not permit detailed discussion of this point. There are limitations, however, to the utility of the idealized concepts under discussion, regardless of mathematical form, since (a) the source is assumed to have no thickness; (b) the source is assumed to be transparent; and (c) secondary effects attendant upon absorption are neglected.

We believe that the supposed complexity involved in using elliptic integrals is more imaginary than real. One can look up and use elliptic integrals with the same facility and convenience as is the case with ordinary trigonometric functions, provided only that tables are available of these integrals, such as the tables of Jahnke and Emde.*

The second general approach employed by the authors was to consider self-absorption in a hollow cylindrical source of finite thickness. This case

* E. Jahnke, F. Emde, "Tables of Functions with Formula and Curves," 4th ed. (Dover, New York, 1945).

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was studied only on the axis of the cylindrical source. The expression developed for the dose rate due to an element of volume of the source could not be integrated in closed form, and consequently recourse was taken to a series expansion and integration term by term, a total of three terms being employed. The convergence of the resulting series of integrals will now be discussed, since this development was also questioned by Dillon. See Eqs. 6, 7, and 8, and Fig. 3 of the article by Lewis, *et al.* The notation used here is defined as for the previous article.

A series expansion of the exponential in the integrand of Eq. 7 is uniformly convergent for finite values of the exponent, which result from finite values for μ, ρ, r, r_1, Z, Z_1, and for r bounded away from zero. In addition, only nonnegative values of the exponent will be considered. The product of the exponential series and finite continuous factors not functions of the number of terms taken will not effect the convergence of the series. Consequently, the series expansion of the integrand may be integrated term by term, and the series of integrals will converge uniformly to the integral of the series. See Courant† and Kaplan.‡ One may also consider Eq. 6 to represent a volume integral, which will have a value no greater than the product of the maximum value of the integrand and the magnitude of the volume over which integration is conducted, as pointed out by Piranian.§ The maximum value of the integrand will be bounded by virtue of the uniform convergence of the series over the region in question.

The integrand series is alternating and for nonnegative values of the exponent, $\mu\ \rho\ (r - r_1)\ \csc\ \phi$, the integral series will also be alternating. This circumstance provides a means of testing rapidity of convergence of the integral series. The series is uniformly convergent, hence absolutely convergent, and is also alternating. If, in addition, the absolute value of each successive term is less than that of the preceding term, then the error incurred by approximating the sum of the series by a partial sum is less in absolute value than the first term neglected.

---

† R. Courant, "Differential and Integral Calculus," vol. I, p. 392 (Blackie and Son, London and Glasgow, 1934).

‡ W. Kaplan, "Advanced Calculus," p. 171, 177, 2nd ed. (Ann Arbor Publishers, Ann Arbor, 1951).

§ G. Piranian, private communication (1954).

Such a circumstance may be difficult to predict in general, but one would anticipate that it would prevail if $\mu\ \rho(r - r_1)\ \csc\ \phi < 1$ holds, since this would result in a ratio of less than unity for the integrand series of this problem. This equation permits a preliminary estimate of the probable conformity of the integral series to the alternating series test. A final check can be achieved by numerical calculation of the terms of the integral series. If these decrease in absolute value for successive terms, then the preceding method of estimating error applies.

In the calibration work reported earlier by the authors, the three-term approximation to the exponential was reported only for those locations in which the preceding test for rapidity of convergence could be applied. It is recommended that some such check be applied to any contemplated applications of such a series expression.

—J. G. Lewis, J. V. Nehemias, D. E. Harmer, and J. J. Martin
Engineering Research Institute
University of Michigan
Ann Arbor, Michigan

AUTHOR'S REPLY: Thank you very much for sending me copies of your letter. . . In the first place, there is little disagreement in our thinking. In regard to the complexity of use of elliptic integrals, if tables in the form of Jahnke and Emde are available, they can be used with facility by most scientific personnel.

Next, insofar as to the validity of the three-term expansion is concerned, it is true as you mentioned in the convergence equation of your letter, that where the value of the exponent is less than one the series converges rapidly and each succeeding term is less than the preceding one, so the error incurred by neglecting any term is less in absolute value than the term neglected. However, in many cases (and this was true for the actual fission-product source discussed by Loeding, *et. al.*¶ where the calculations of radiation intensity showed it to be near the optimum shape) the value of the exponent $(\mu\rho(r - r_1)\ \csc\ \phi)$ exceeds one. Thus, since convergence is very slow for exponent values above one, three terms are not adequate.

—Ira G. Dillon
Chemical Engineering Division
Argonne National Laboratory
Lemont, Illinois

¶ J. W. Loeding, E. J. Petkus, G. Yasui, W. A. Rodger. Preparation of a fission-product kilocurie radiation source, NUCLEONICS **13**, No. 5, 15 (1954).

TABLE OF CHAMBERS FOR USE ON VICTOREEN CONDENSER R-METER

Chambers for use on Model 70	Range (Roentgens)	Intensity** Limits (r/sec)	Rated Accuracy (Model 70)	Intended Uses (Kev eff)	Wall Material	Volume (cm^3)	Nominal Wall Thick. (mg/cm^2)	Minimum Energy of Electrons to Traverse Wall (Kev)
LOW ENERGY CHAMBERS								
128	250	10.0		4-8	Brass plus Nylon Wind.	.175 to .190	0.6	16
365†	250	40.0	±10%	10-30	Nylon	.175 to .190	14.5	100
MEDIUM ENERGY CHAMBERS								
188	.025	8×10^{-5}	±10%	30-400	Bakelite	1450	220	620
130	0.25	3×10^{-3}	±10%	30-400	Bakelite	177	220	620
227	1.0	0.065	±10%	30-400	Bakelite	41	220	620
633	2.5	0.1	±10%	30-400	Bakelite	17	220	620
228	5.0	1.7	±10%	30-400	Bakelite	8	220	620
326	10.0	1.7	±10%	30-400	Polystyrene	6	168	510
70-5	25.0	15.0	± 2%	30-400	Bakelite*	1.75 to 1.90	80	320
					Nylon		67	270
131	100.0	25.0	± 2%	30-400	Bakelite*	0.44 to 0.48	104	360
					Nylon		89	330
154	250.0	40.0	± 2%	30-400	Bakelite*	.175 to .190	104	360
					Nylon		89	330
133*†	1000.0	1000.0	±10%	30-400	Polystyrene	.044	111	380
132*†	2500.0	4000.0	±10%	30-400	Polystyrene	Approx. .018	85	320
HIGH ENERGY CHAMBERS								
552	2.5	0.1	± 5%	400 to 2000	Nylon	Approx. 9.7	450	1050
553	25.0	15.0	± 5%	400 to 2000	Nylon	1.75 to 1.90	450	1050
621	100.0	25.0	± 5%	400 to 2000	Nylon	0.44 to 0.48	450	1050
ISOTOPE ASSAY CHAMBER								
503	---	---	±10%	I-131 & Au-198	Brass			
SKIN EQUIVALENT CHAMBERS								
576	0.25	0.003	±10%◆	Mixed Beta Gamma	Kodapak	170.0	7	70
577	2.5	0.1	±10%◆		Kodapak	17.0	7	70
578	25.0	10.0	±10%◆		Kodapak	1.7	7	70

*Discontinued.

**These intensity limits are based on full scale reading and may be increased if readings less than one half scale are taken.

†Sold only with understanding of limitations.

◆This rated accuracy is based on use with a protective plastic sleeve 1/16" thick.

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There, he took a leading part in technical work that led to current widespread use of ammonium nitrate. Recognizing his leadership in process development for extracting alumina from clay, the American Institute of Chemical Engineers voted him the William H. Walker Award in 1946.

At WALTER KIDDE NUCLEAR LABORATORIES, Dr. Miller is Laboratory Director. Under his direction, physicists, chemical engineers and chemists, mathematicians, metallurgists and other specialists explore such problems as the development of a portable nuclear power source for industry. Or ultra-high flux heat transfer – a field in which WKNL has pioneered. Or development of rugged detection devices for atomic bomb test work.

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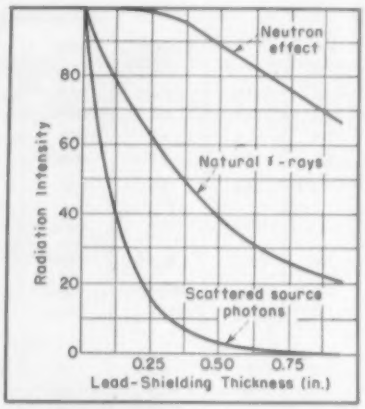
Patents

Cation-Exchange Well Logging

Although well logging by measuring natural gamma activity distinguishes shale from limestone or sandstone, it fails to distinguish between limestone and sandstone or to differentiate types of shale strata adequately. One cannot always recognize the same geological formation in related wells nor obtain information useful in secondary recovery and acidizing operations.

In U. S. 2,691,109, issued to George B. Bernard and assigned to Pure Oil Co., formations can be distinguished by the cation-exchange capacities of the clays forming part of the formations. In contacting clay with radionitrogen-labeled ammonium chloride, ammonium ions quantitatively replace ions such as Ca^{++}, Na^{+}, and K^{+}. After flushing with water to remove excess solution, the activity of the clay is measured. Other useable radioactive materials are radionitrogen-labeled ammonium acetate and radiobarium-labeled barium acetate.

A 1-hr contact time is sufficient for complete cation exchange. Clay deposited over a considerable area during a given sedimentation period has the same cation-exchange capacity throughout the area, regardless of its succeeding environment changes, and produces the same characteristic variations on logs of neighboring bore holes.



ATTENUATION of γ-ray components in neutron well logging

Neutron Well Logging

Neutron well logs, made with a source of 300–500 mc of radium mixed with powdered beryllium, permit neutron-activated gamma-ray measurement of the strata. However, scattered gamma radiation of the source's daughter products introduces considerable error, particularly since the scattering varies with the borehole size, rock density, casing thickness, density of the fluid in the well, etc.

The solution to the problem suggested in U. S. 2,691,741 (issued to Gilbert Swift and assigned to Well Surveys, Inc.) utilizes a detector shield that greatly attenuates scattered gamma radiation with much less effect on the neutron-activated gammas (see graph). In the design described here, an ionization-chamber-type detector is shielded by a material enclosed in a steel envelope.

Although a number of shielding materials are suggested, the two claims in this patent are directed to tungsten sintered with a binding metal, such as copper.

Gamma-Ray Detector

U. S. 2,692,339, issued to Ernest Franklin and assigned to the National Research Development Corp. (London, England), describes a gamma-ray detector that, by means of three ionization chambers, provides uniform statistical accuracy for three different counting rates.

Each chamber triggers its own cold-cathode gaseous-discharge tube. The outputs of all three tubes, integrated separately, operate a single meter.

The statistical accuracy is proportional to the square root of the product of the counting rate and the time during which the pulses from the tubes are integrated. When the counting rate is changed, a different tube is used with a correspondingly altered integrating time, so that the statistical accuracy is the same for each of the three tubes.

NEWSMAKERS

Curtis A. Nelson has been named director of AEC's new Inspection Division, created under section 25c of the Atomic Energy Act of 1954. He will report directly to the general manager. **Robert C. Nelson** succeeds him as manager of the Savannah River Operations Office.

Niels Bohr has submitted his resignation to the University of Copenhagen, Denmark. His son, **Philip Bohr,** is expected to succeed him.

Wilbur B. Pings now heads Vitro Laboratories' department of chemical research and development. He was research director for Air Products, Inc.

Lawrence C. Widdoes has returned to Monsanto Chemical Co. to take charge of design of a large dual-purpose reactor. Since August, 1953, he has been on leave of absence to serve as project engineer on the University of Michigan research reactor. **Russell B. Mesler** succeeds him at Michigan.

Joseph Silverman, formerly a staff physical chemist, has been promoted to head of the research department, laboratory division, for Walter Kidde Nuclear Laboratories, Inc.

James Schulman, R. J. Ginther, C. R. Horner, C. C. Klick, S. C. Rainey, J. Cryden, L. W. Evans, A. Lovoff, W. F. Gray and **R. Alger** have received Department of Defense awards totalling $2,400 for developing the glass dog-tag dosimeters now being distributed to Naval and military personnel. Development was carried out primarily at Naval Research Laboratory (NU, Oct. '53, p. 52).

Gordon Dean, former AEC chairman now with Lehman Brothers, has been elected to the board of directors of Ketay Instrument Corp.

M. D. Hooven, Public Service Electric and Gas Co., Newark, N. J., has been nominated as president of the American Institute of Electrical Engineers.

Roy B. Snapp, formerly secretary to the Atomic Energy Commission, has resigned as assistant to AEC Chairman Strauss to establish his own office with the firm of Gall, Lane and Howe in Washington. He will specialize in legal aspects of atomic energy.

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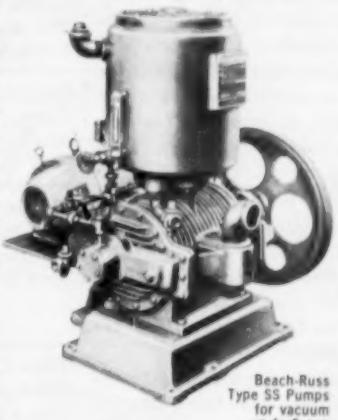

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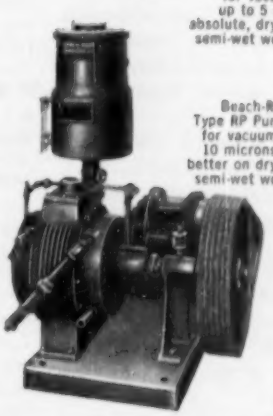

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Disposable Air Filters

A NUCLEONICS Special Survey

THE TABULATION of disposable air filters presented here is the result of a NUCLEONICS survey of air-filter manufacturers. All of the filters listed may be regarded as being disposable, or having disposable media, although some were designed to be washed and reused. This is not a complete listing of all filters available.

These filters are useful in a large variety of situations where radioparticulates must be removed from air. Consideration must be given to the particle size expected, since filter efficiency is a function of particle size (even chicken wire is 100% efficient for baseballs). Even in situations where a filter of high efficiency for 1-μ particles is called for, it may be economical to precede it with a lower efficiency filter to reduce the burden of larger particles in the air.

The footnote to the table gives further information about the efficiency tests used for the tabulated filters. Standard texts describing the tests are in the bibliography (*1–8*).

No attempt has been made to indicate corrosion resistance; this is affected by many variables. Some judgement can be made from the construction materials listed for each filter. Most suppliers offer special materials as required.

Some firms surveyed offer filter media only, and thus are not included. However their products are useful for laboratory-designed filters. Included are:

Metal Textile Corp., Roselle, N. J. (Knitted wire of any metal that can be drawn.)

Millipore Corp., Watertown 72, Mass. (Cellulose-ester papers with pore sizes as low as 0.45 μ.)

Otto H. York Co., 6 Central Ave., W. Orange, N. J. (Knitted metal mesh for entrained-liquid filters.)

Other Air Cleaners

In a survey of this limited scope, many useful and important air-cleaning devices are necessarily neglected. Equipment such as scrubbers, cyclonic

Supplier's address	*Model**	*New filter cost ($)*	*Dimensions*				*Rated flow*	*Pressure drop at rated flow*	
			Width (in.)	*Ht. (in.)*	*Depth (in.)*	*Wt. (lb)*	*(ft³/min)*	*New (in. of water)*	*Replacement (in. of water)*
American Air Filter Co., Louisville, Ky.	Amerglas		25	20	2	20	1,000	0.1	0.5
	A-50FG2		27	27	36	180	1,000	0.9	3.0
	PL-24-G		24	24	8¾	33	1,000	0.028	0.5
Cambridge Filter Corp., 738 Erie Blvd., E. Syracuse, New York	1A-25	16.50	8	8	3 1/16	3	30	1	2
	1A-1000	75.00	30	24	11½	47	1,250	1	2
	1A-250	35.00	24	24	3 1/16	12	250	1	2
	43A-35	53.00	24	24	12	31	1,000	0.16	0.60
	43A-85	57.00	24	24	12	31	1,000	0.22	0.60
	43A-95	58.00	24	24	12	31	1,000	0.35	0.80
Continental Air Filters, Inc., 2520 Helm St., Louisville, Ky.	CA-24	30.00	24	24	8¾	40	1,000	0.10	0.5
	DY	6.80	20	25	1	2	1,000	0.16	0.5
Drico Industrial Corp., 559 W. 35 St., New York, N.Y.		1.50	20	25	2	1	1,000	0.15	0.50
			10	10	2	0.5	200	0.15	0.50
Flanders Mill, Inc., Riverhead, New York	2A		8	8	3 1/16	3¾	30	1	10
	2B		8	8	5⅞	5	60	1	10
	2F		24	24		11½	1,000	1	10
	1A		8	8	3 1/16	3	30	1	10
	1D		24	24	5⅞	24	575	1	6
	1H		24	30	11½	44	1,200	1	8
Fiber Glass Div., Pittsburgh Plate Glass Co., 1 Gateway Center, Pittsburgh, Pa.	1S		20	20	2	1	1,000	0.15	0.5
	Std.		20	20	2	1	600	0.15	0.5
P. M. Lennard, 671 Bergen St., Brooklyn, N.Y.	50	3.00	3 o.d.		7	0.2	95	0.5	
	51	3.00	3 o.d.		7		105	0.75	
Mine Safety Appliances Co., 201 N. Braddock Ave., Pittsburgh, Pa.	E-2	10.00	8	8	5⅞	3.0	50	1	2
	E-1	10.00	8	8	3 1/16	1.5	35	1	2
	E-4	35.00	24	24	5⅞	29.0	500	1	2
	E-6	50.00	24	24	11½	37.0	1,000	1	2
Research Products Corp., 1015 E. Washington Ave., Madison, Wisconsin	201	1.75	20	25	2	2.5	1,000	0.1	0.2
	202	1.50	20	20	2	2.1	800	0.1	0.2
	205	1.35	15	20	2	1.5	600	0.1	0.2
Wilson & Co., 4,100 S. Ashland Ave., Chicago 9, Ill.		1.38	20	20	2	0.9	350	0.1	0.5
		1.08	20	20	1	0.5	350	0.06	0.3

* Most manufacturers listed make many more models than the representative ones that

† Efficiency of an air filter is meaningless without specification of the method by which and ASHVE tests use standard dusts, measure efficiency by means of weight; DOP test dust, measures efficiency by blackening of dust spot.

Dust load at replacement (grains)	Efficiency† Measured value (%)	How measured	Filter construction	Filter medium: Sell alone?	Filter medium: Cost ($/ft²)	Max. Temp (°F)	Remarks	Other media available
	85	AFI	Coated glass.	Yes				
	91	NBS	1¼-μ glass fibers.	Yes			Deep Bed.	25G, 75 and 100FG;
	92	AFI	Bonded glass.	Yes	0.50	250	Pleated frame	Airmat paper
	99.95	DOP	Cellulose-asbestos;	Yes		220		All-glass,
	99.95	DOP	kraft-paper separators.					Al separators,
	99.95	DOP						1,000° F
	35	NBS	All glass;				Replacement	
	85	NBS	Al separators.	Yes		250	cartridges,	
	95	NBS					$12–16	
6,000	95.6	ASHVE	Nonhygroscopic	Yes	0.40	220	Pleated Al frame	
3,500	75	ASHVE	synthetic fibers; steel frame.	Yes		220		
	85	ASHVE	Glass fibers.	Yes	0.12	320		No
	85	ASHVE						
	99.95	DOP	Glass fibers;	No		1,000	Tightly pleated	
	99.95	DOP	Al separators;				medium	Yes
	99.95	DOP	steel frame.					
	99.95	DOP	CWS #6; 9-pt kraft	No		225		
	99.95	DOP	paper separators;					
	99.95	DOP	wood frame.					Yes
3,500	90	AFI	Glass fibers;	Yes		350		
4,000	70		tin plate and paper frame.			350		
	93	Com-	FG25,	Yes		400		Lead-lined
	93	pared	FG50.					cartridge
700	99.95	DOP	Silened CWS #6;	No				E glass fibers
500	99.95	DOP	cardboard separator;					
7,000	99.95	DOP	wood frame.			180	1,000° F model	
14,000	99.95	DOP					offered	
7,200	92	Weight—	Expanded kraft	Yes	0.20	150		Washable Al
5,760	92	200 mesh	paper.					
4,350	92	dust						
5,400	95.2	ASHVE	Animal hair;	Yes		150	Sizes to 40 in.	No
2,500	70	ASHVE	cardboard or wire frame.				square	

are listed here. Write supplier for further information.
measured. Standards for the tests are given in the bibliography as follows: AFI, (*5*), ASHVE, (*6*), DOP, (*7*), NBS, (*8*). In brief: AFI uses uniform 3-μ dioctyl-phthalate smoke, measures efficiency with instrument that measures light-scattering; NBS test uses atmospheric

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cleaners, washable filters, electric precipitators, etc. are discussed in references given (*1–4*).

Manufacturers of high-efficiency electrostatic filters include: Air-Maze Corp., 25000 Miles Rd., Cleveland, O.; American Air Filter Co., Louisville, Ky.; Radex Corp., 2076 Elston Ave., Chicago 14, Ill.; Trion Inc., 1000 Island Ave., McKees Rocks, Pa.; Westinghouse Electric Corp., Sturtevant Division, Hyde Park, Boston 36, Mass.; Western Precipitation Corp., 1004 W. Ninth St., Los Angeles 15, Calif.

Other manufacturers of air-cleaning equipment who responded to the survey are:

Air Devices Inc., 185 Madison Ave., New York 17, N. Y. (Agitair washable viscous impingement filters.)

Air & Refrigeration Corp., 475 Fifth Ave., New York 17, N. Y. (Capillary air washers.)

Akron Rubber Co., 35 Warren St., New York 7, N. Y. (Pliotron self-charging electrostatic filters of shredded polyethylene.)

* * *

Copies of this survey, at 10 cents each, can be obtained from Reprint Department, NUCLEONICS, 330 West 42nd St., New York 36, N. Y.

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6. "Transactions of the American Society of Heating and Ventilating Engineers," vol. 39, p. 225 (ASHVE, New York, N. Y., 1933)
7. Method for determining DOP smoke penetration and air resistance of particulate filters (Army Chemical Corps, Edgewood Arsenal, Maryland)
8. R. S. Dill in "Transactions of the American Society of Heating and Ventilating Engineers," vol. 44, p. 379 (ASHVE, New York, N. Y., 1938)

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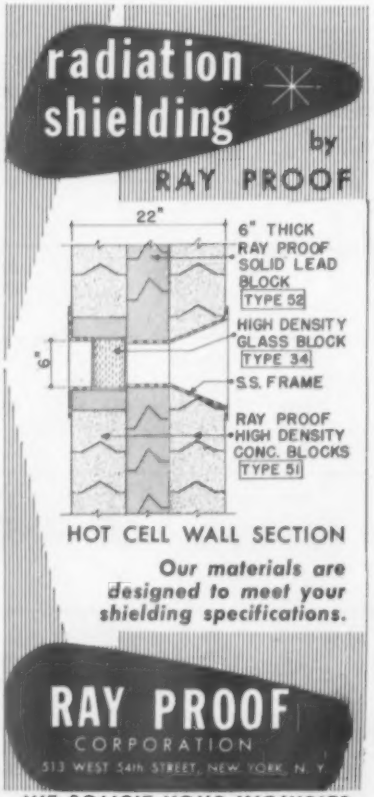

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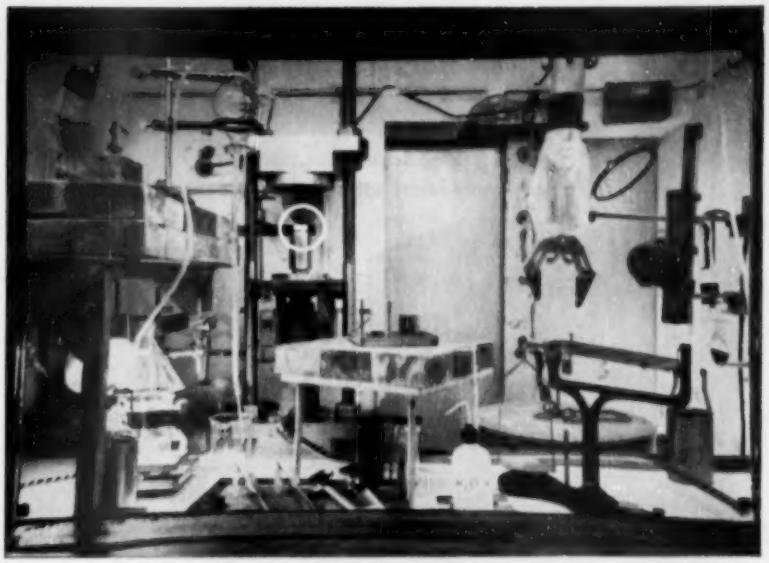
• The El-Tronics prospecting counters range from a pocket-sized, earphone-indicating Geiger counter to a scintillation detector for car or aerial surveys. Between the two are Geiger models with headphones and flashing lights, flashing light and dial, and three-range dial plus external hand probe. Some models can be equipped with a well-logging probe. Three scintillation counters for area surveys complete the line.—El-Tronics, Inc., Fifth and Noble St., Philadelphia 23, Pa.

• Model RM2N Geiger counter has scale reading to 0.25, 2.5 and 25 mr/hr, also 500–50,000 cpm. Neon-



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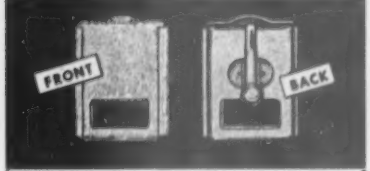

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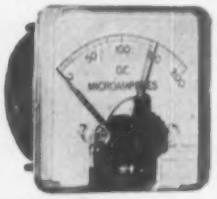

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Suggested circuits for meter-relays and complete specifications including prices are covered in new 16-page Bulletin G-6, which you can get by writing Assembly Products, Inc., Chesterland 28, Ohio.

Booth 311, I. R. E. Show, March 21-24

light and headphone also respond to radiation signals. Geiger tube is mounted on 3.5-ft cable. Model RDN has internally mounted tube and no meter. The Geiger flasher, RFN, has only headphone indication. Batteries are externally mounted.—Nucleonic Co. of America, 196 DeGraw St., Brooklyn 31, N. Y.

Scintillation Counters

These two survey scintillation meters are for field use. Both use NaI crystals.

• Time constants of 0.2, 1.0, and 25 sec are selectable on the Scintillascope (above, top). Crystal and photomultiplier are shock mounted. Five range switch selects counting rates from 0–100 to 0–10,000 cps. Ore calibration scale is provided. Weight is 6.5 lb.—Fisher Research Laboratory Inc., 1961 University Ave., Palo Alto, Calif.

• Having a 1.5 in. crystal, the model 111B portable scintillator (above, bottom), can be used for aerial surveys. Meter has an mr/hr and a per cent scale for U in ore determination. Instrument weighs 7¾ lb.—Precision Radiation Instruments, Inc., 4223 W. Jefferson Blvd, Los Angeles 16, Calif.

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μa, depending on input. Circuit is shown in NUCLEONICS, June '50, p. 56.—Edko Electronics Engineering Co., 202 Grand St., Brooklyn 11, N. Y.

Versatile Ratemeter

Discriminator-controlled ratemeter RM-1B (above) has range of 100–10^5 cpm and discriminator to set minimum signal amplitude recognized. Probable error may be selected as 1, 3, or 10%. Alarm circuit will actuate built-in relay at any selected rate. Meter will count + or − pulses or sine-wave signals. Model RM-1B-103 has high-voltage power supply and amplifier, plus above features.—Technical Measurement Corp., 140 State St., New Haven, Conn.

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Etched-circuit flip-flop. Operating at 0–100 kc, the Z-91000 flip-flop plugs into standard 15-contact printed circuit connector. It requires 200 v d-c at 3.5 ma. Unit weighs 1.5 oz.—Eeco Production Co., 827 S. Vermont Ave., Los Angeles 5, Calif.

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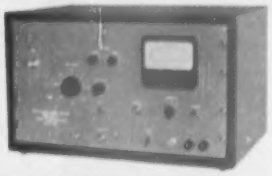

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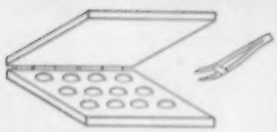

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INQUIRIES INVITED

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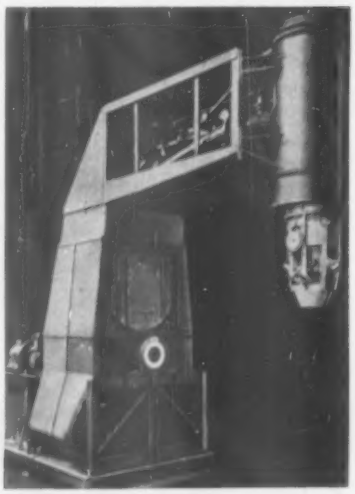
booster pumps are sized 4, 6, 10, and 16 in.—Stokes Machine Co., 5500 Tabor Rd., Philadelphia 20, Pa.

•

Distilled-water air filter. With replaceable cartridge, the Ventigard removes all particles above 0.2 micron and gases including CO_2 from air entering distilled-water tanks. Cartridge lasts for 60 days or 1,000 gal of water. Unit is made for metal and glass tanks, can be added to present ones.—Barnstead Still and Sterilizer Co., 222 Lanesville Terrance, Forest Hills, Boston 31, Mass.

Internal-standard flame photometer. For determining Na, K, and Li, the Norelco flame photometer adds a known amount of Li to unknown and measures ratio of Na or K to Li. Sensitivity is adjustable from 5 ppm to 10 milliequivalent/l Na or K. Single specimen is used for both Na and K. Separate sensitivity controls are provided.—North American Philips Co., 750 S. Fulton Ave., Mount Vernon, N. Y.

RADIOACTIVITY MATERIALS AND APPARATUS



Particle Accelerators

A portable Van de Graaff, and two linear accelerators have been announced as commercially available.

• Portable 1-Mev Van de Graaff for industrial radiography, is 6-ft long by 3-ft diameter. Weight is 2,500 lb. The focal spot is ¾-mm diameter allowing use for 5-in.-thick metal with short exposure times. A 4–7-Mev linear accelerator is available. Beam power is about 1 kw in the range 4–6

Mev. Unit is compact and can be flexibly mounted at a distance from its r-f power supply and controls.—High Voltage Engineering Corp., 7 University Rd., Cambridge 38, Mass.

• The 4-Mev Orthotron has an adjustable diaphragm to define beam. Machine (p. 98) swings in 135° arc. Unfiltered X-ray output is 330 r/min at 1 meter from target. Machine focal spot is about 5 mm.—Metropolitan-Vickers Electrical Export Co., St. Paul's Corner, 1–3 St. Paul's Churchyard, London, E. C. 4, England.

•

High-specific-activity isotopes. Cyclotron-produced isotopes of high-specific activity are available. Activities are: Fe^{59}-10 c/g, Cr^{51}-50 c/g, Zn^{65}-20 c/g. Other products are radiogold colloids, activated-I human serum albumen. Other cyclotron isotopes are available.—N. V. Philips-Roxane, Isotopes Laboratory, P. C. Hooftstraat 171–177, Amsterdam, The Netherlands.

Pocket-sized radiography calculator. Mark II exposure calculator has scales for Ce^{137}, Tm^{170}, Co^{60}, Ir^{192} and radon. Scales are in inches.—M. Falk and Co., 5 Victoria St., London S. W. 1, England.

Isotope carrying pot. Shielded by about 1 in. of lead, stainless-steel carrying pot has free volume of 100 cm^3. It has a lid and is easily decontaminated and sterilized.—Technical Specialties Inc., 50 W. Maple St., Columbus 15, Ohio.

Food-contamination standard. Standards containing 9×10^{-2} μc of U for comparison with possibly contaminated water or food allow safety determination. Activity is equal to FCDA 10-day emergency consumption limit. Stand allows reproducable geometry.—Tracerlab, Inc., 130 High St., Boston 10, Mass.

Labeled aniline. Uniformly labeled with C^{14}, aniline is available in a 1 mc/millimole activity. Three sizes, 1, 0.5 and 0.1 mc are supplied.—Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill.

INDUSTRY NOTES

▶**Phillips Petroleum Co.,** Bartlesville, Okla., and **Consolidated Engineering Corp.,** Pasadena, Calif. have concluded an agreement under which Consolidated will market plant analy-

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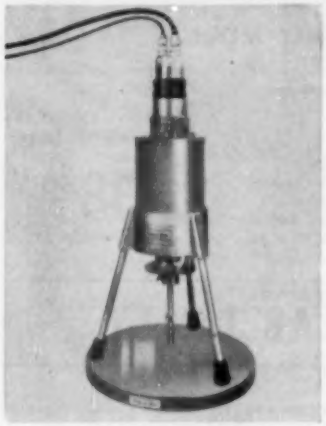
SCINTILLATION CRYSTALS and EQUIPMENT



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sis and control instruments developed by Phillips. Infrared gas analyzers, differential refractometers, and ultraviolet analyzers will be marketed.

▶**Beckman Instruments Co.,** Fullerton, Calif., has acquired **Specialized Instruments Corp.** and **Spinco Service Co.,** both of Belmont, Calif. They will be operated as the Spinco Division. Products are instruments for advance research, such as an ultracentrifuge.

▶**Daystrom, Inc.,** Elizabeth, N. J. now owns a majority stock in **Weston Electrical Instrument Corp.,** Newark, N. J. Weston manufactures nearly 900 varieties of electronic apparatus.

▶**Precision Radiation Instruments, Inc.,** Los Angeles, Calif. has added 10,000 ft² to its manufacturing facilities. Firm makes portable radiation equipment.

▶**General Ultrasonics Co.,** Hartford, Conn. has been incorporated to make and market the Rich-Roth 400 ultrasonic generator and associated transducers.

LITERATURE AVAILABLE

Printed-circuit vacuum gage. Designed around printed circuit, type TG-029 vacuum gage is calibrated for air from 1-1,000 microns, on one direct-reading scale. New gage tube, TG-77 eliminates fragile nature of junction weld.—Consolidated Vacuum Corp., 735 Ridge Rd. W., Rochester 3, N. Y.

Radiation instruments. Catalog B lists complete line of radiation detectors and accessories, including scintillation counters. Another catalog describes medical instruments for radioisotope use. 28 and 12 p.—NRD Instrument Co., 6425 Etzel Ave., St. Louis 14, Mo.

Aluminum casting alloys. Handbook gives material on metallurgy and casting practices, plus cross-index of all important specifications. Effect of alloying is discussed. 60 p.—American Smelting and Refining Co., 120 Broadway, New York 5, N. Y.

Production recorder. Bulletin 541 describes recorder that makes permanent records of machine speed or rates, by counting production units. 16 p.—Electric Tachometer Corp., 2218 Vine St., Philadelphia 3, Pa.

RAW MATERIALS

PERU: rich ore deposit verified. A uranium oxide content of 2.46%, with some assays as high as 3.7%, has been found by government geologists in ores from the Colquijirca mines near Cerro de Pasco. Mines are owned by the Fernandini interests. U. S. AEC geologists cooperated in assays.

UNITED STATES: calls present uranium production adequate for 1980; new claims acquired. John R. Menke, president of Nuclear Development Associates, told the National Western Mining Conference last month that "it would seem that the world is producing this year an amount of uranium very similar to the total peacetime need for uranium in 1980."

¶ Western Gold and Uranium, Inc., has acquired 55 claims covering 1,400 acres in Utah from William Rogers and partners. Ore deposits are shallow enough for wagon-drill proving; development of the property started last month.

CANADA: British back $41-million development. Most of the new $41-million financing for development of Algom Uranium Mines, Ltd., northern Ontario property comes from a British syndicate headed by Rio Tinto Co. Algom has a $207-million agreement with the Canadian government for sale of its ore.

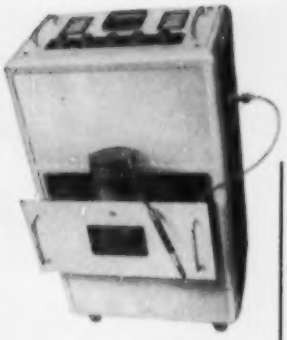
GERMANY: added ore deposits found. Three more regions of the southern Black Forest (state of South Baden) contain deposits of uranium ore, according to a preliminary survey.

SOUTH AFRICA: two processing plants start working, survey of western areas starts. Two new uranium ore processing plants—at Luipaards Vlei and Vogelstruisbult—recently began operations; two more will go into service shortly in the Orange Free State gold fields.

¶ With surveys of the Rand and Free State gold areas completed for uranium and thorium, the Atomic Energy Board is starting a car-borne survey of the 40,000-square-mile arid western area of the country. Only deposit being exploited in this area is at Van Rhynsdorp.

INDIA: cash awards spurs discovery of new minerals. A new deposit of beryl ore in Andhra State is the first discovery attributed to the government's offer of cash awards.

Radiological Instruments



Ionex Ionisation Meter

A universal dosimeter for measuring dose rate and accumulated dose of X and gamma radiation. Full scale deflections for: 300 ur–1000 r and 30 ur/min–1000 r/min. A precision instrument for the hospital physicist. Leaflet D8–118.

Baldwin Farmer X-Ray Dosimeter

A precision sub-standard instrument used for checking tube outputs and calibrating dosimeters for routine therapy. The range is 0–60 r over the quality range 40kV to 2MV. A radio-active reference source is available for checking long term stability. Leaflet D8–125.

Baldwin Farmer Radiological Electrometer Type R.B.

This instrument serves to charge detachable ionisation chambers and subsequently, after exposure, to measure the remaining charge. Almost any type of ionisation chamber can be used with this Electrometer. Leaflet D8–110.

Protection Electrometer

Small pocket ionisation chambers are used with this instrument to give immediate indication of X or gamma dose received by personnel. Leaflet D8–122.

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HEALTH PHYSICIST, B.S. Degree, six years experience with a major AEC project, desires position with smaller firm in nuclear field. PW-5671, Nucleonics.

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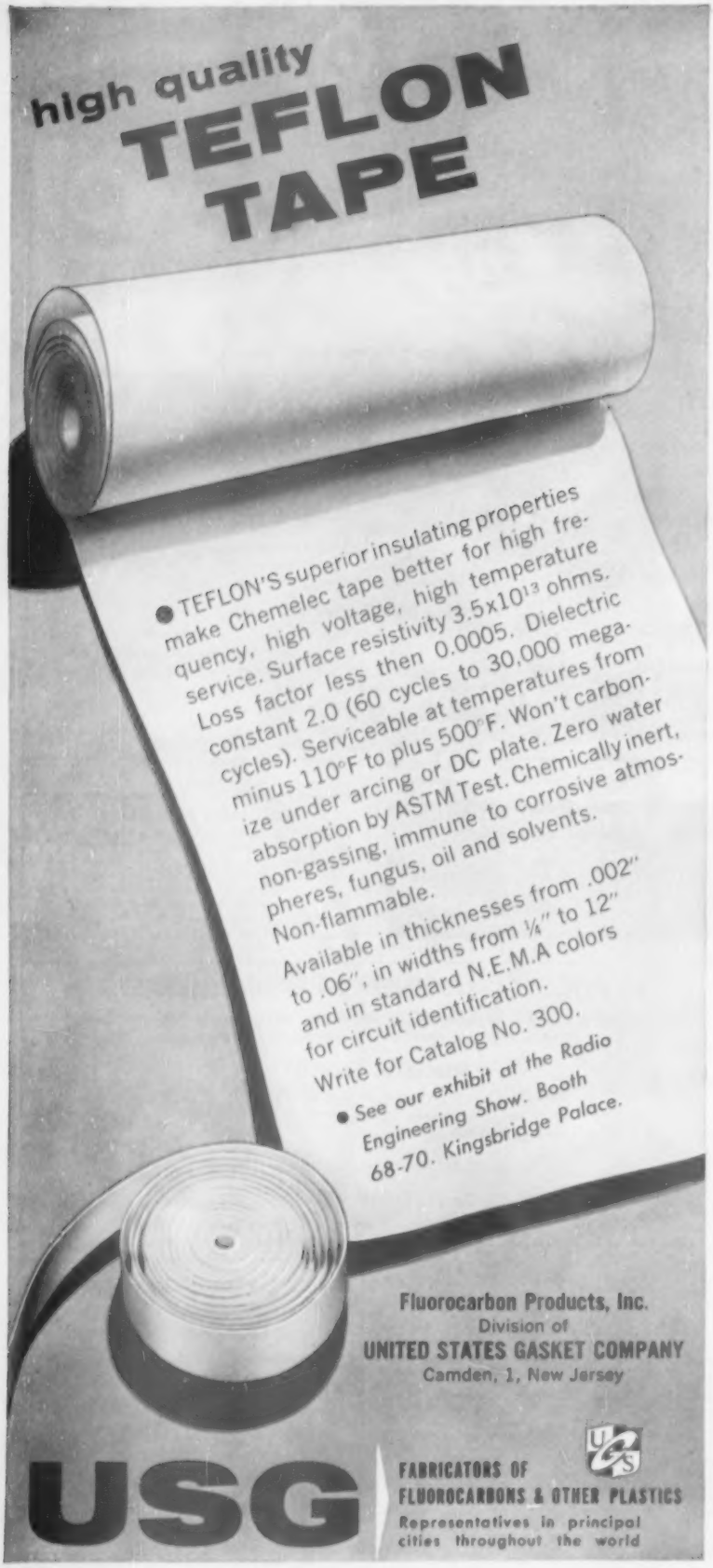
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EMPLOYMENT 101

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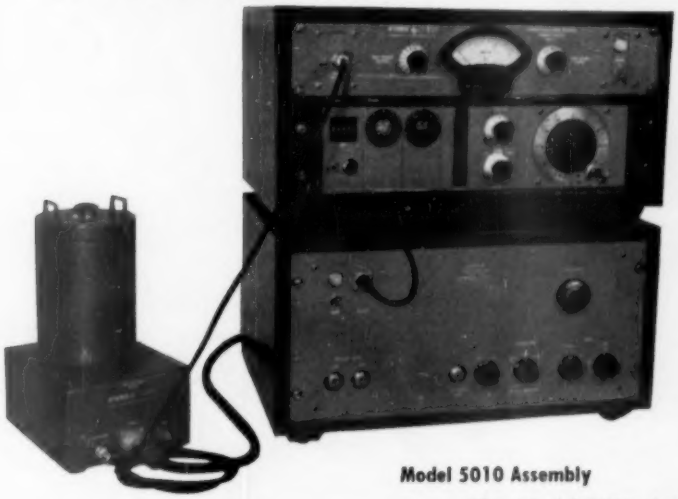
BENCH TYPE *Scintillation Sample Counting* ASSEMBLY

Provides a complete basic laboratory facility for counting gamma radiation from samples of gamma emitting materials.



Model 5010 Assembly

FOR APPLICATION IN THESE FIELDS:

- Chemical Analysis
- Physical Studies
- Biological Tracing
- Medical Examinations
- Industrial Research

TYPICAL OPERATIONS UTILIZING THE MODEL 5010 ARE:

- Activation Analysis
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- Clinical Examination of Blood and Tissue Samples
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- Distribution Studies of Trace Elements in Plant Structure

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Complete specifications of the Model 5010 Assembly are contained in Bulletin 5010-1—available upon request.

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- Highly Linear Amplifier (Model 218) having precision Pulse Height Discriminator and Bandwidth controls.
- Automatic Scaler (Model 131) features: Pre-set automatic timing; 5 microsecond resolution; Scale of 1000 (Decade) plus 4-digit Register; low power, low heat, cold cathode Glow Tubes in improved and simplified circuits for unusual reliability and for long life.
- Bench Type Scintillation Detector (Model 810) with Well Crystal for receiving test tube samples; Shielded against background radiation.

A gamma-emitting sample placed in the well of the Scintillation Detector causes it to produce electrical output pulses according to the radiation intensities. A highly stable High Voltage Power Supply provides the very closely regulated operating potential required for the Detector. Output pulse levels are amplified in a Linear Amplifier to the amplitude required for Scaler operation. The Scaler totalizes and displays the count of pulses received during an exact pre-set time interval. The count is read directly from the register and illuminated electronic decades.

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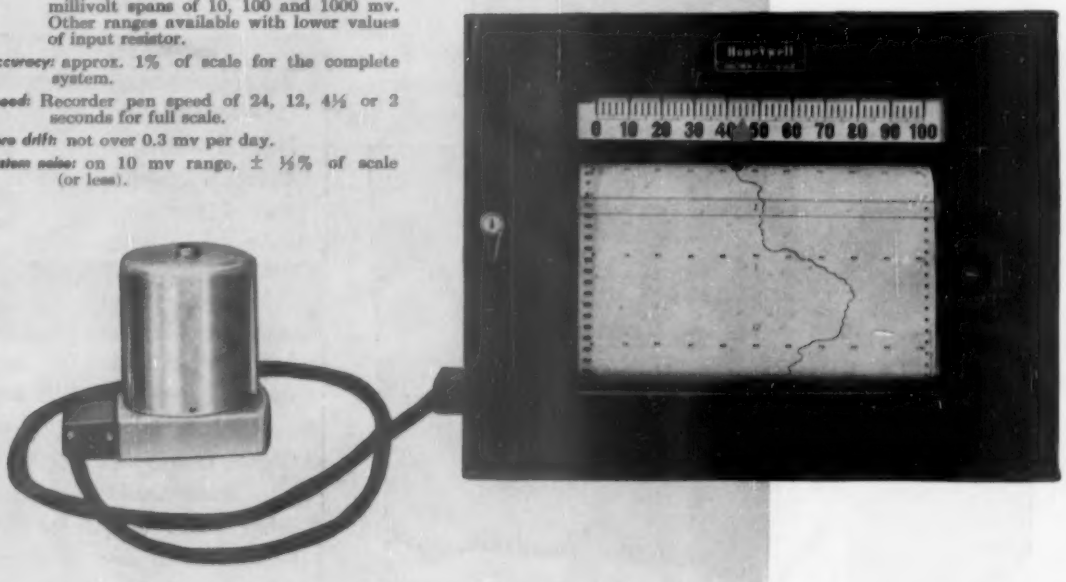
Accuracy: approx. 1% of scale for the complete system.

Speed: Recorder pen speed of 24, 12, 4½ or 2 seconds for full scale.

Zero drift: not over 0.3 mv per day.

System noise: on 10 mv range, ± ½% of scale (or less).



THE Brown Electrometer was designed specifically for recording extremely low level currents such as those produced by ionization chambers. It provides an accurate, sensitive way to obtain continuous, automatic records of currents as small as 10^{-15} ampere. By utilizing the "rate of charge" method, the Electrometer can measure currents down to 10^{-16} ampere.

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